

EUBANK • RAMSAY • RICKARD

PHYSICS

FOR SECONDARY SCHOOLS

ALBERTA EDITION

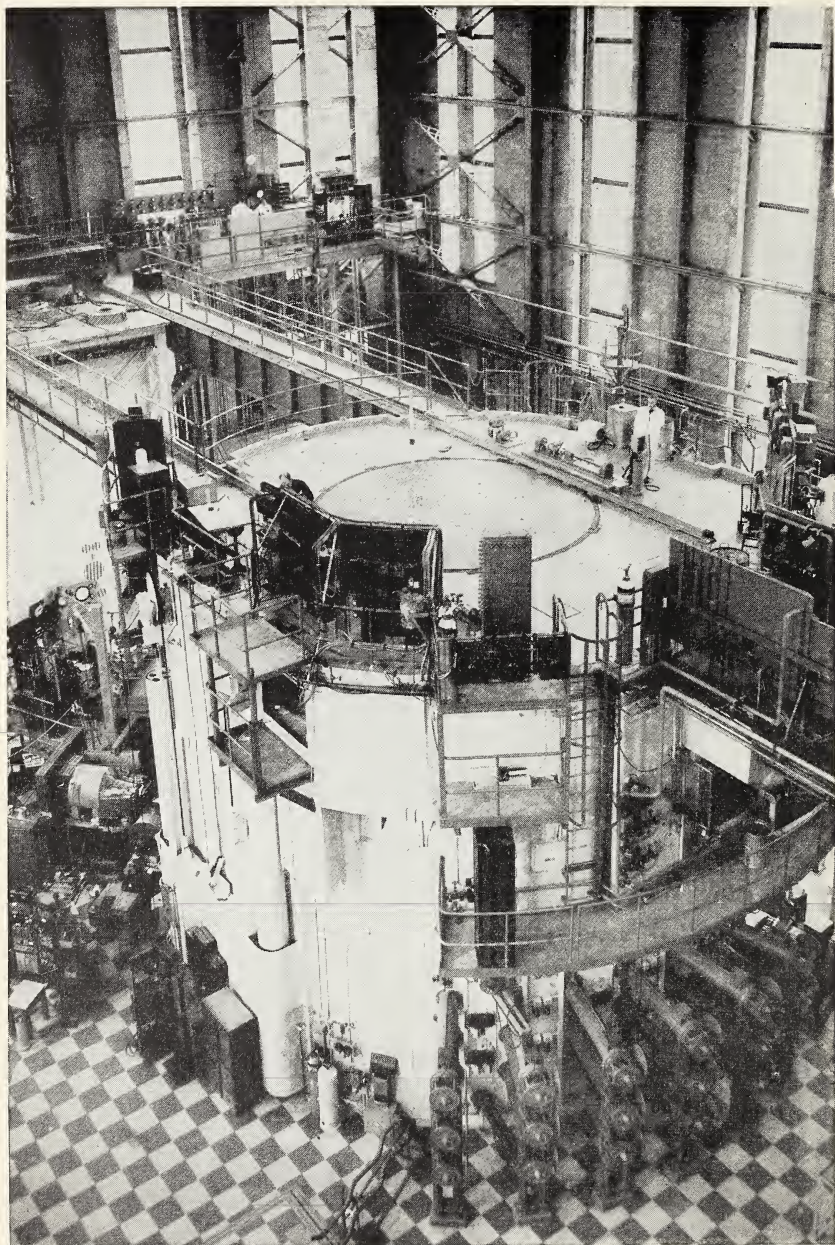
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PHYSICS FOR SECONDARY SCHOOLS



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PHYSICS

FOR SECONDARY SCHOOLS

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Authorized in Alberta

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PREFACE

The most striking fact in the modern world is the development of our knowledge of physics. All machines and appliances result from the application of that knowledge. This text attempts to give an insight into a few fundamentals of the subject and an understanding of some of their applications. These have been presented in a clear, concise and yet sufficiently comprehensive manner to meet the needs of both student and teacher. Specifically designed to cover the needs of Alberta schools in introductory Physics, the text includes supplementary material which makes provision for the above average student.

Physics should be an experimental course and each unit has therefore a concluding chapter of experiments. The apparatus suggested is simple enough to enable most of these to be carried out by the pupils themselves. We believe this special feature of the text will encourage a scientific outlook in pupils and save much valuable time for the teacher.

The need for accuracy and precision in making observations, taking measurements, making calculations and reaching conclusions, is constantly emphasized. To aid in this, a section is included on accuracy of measurement and the use of approximate numbers. Pupils are expected to work all mathematical problems, including the results of their experiments, in accordance with these principles. Sample solutions for each new type of mathematical problem are given throughout the text. In these, as well as in the answers provided in the back of the book, the rules for significant digits have been consistently observed.

There are many features which the authors hope will be useful to teachers and pupils alike. All right-hand pages are clearly marked with section numbers so that desired information may be quickly found. While the authors believe that this and many other features will recommend the book to its users, they recognize that improvements and revisions will be necessary in future editions. To this end they cordially invite comments and suggestions from teachers who have used the book in their classrooms.

We acknowledge gratefully the efforts of those friends and colleagues who helped in the preparation of this text. Much of the material contained in Chapters 5 and 8, the appendix, and the glossary, has been contributed by Mr. S. W. Radomsky of Strathcona Composite High School,

PREFACE

Edmonton, and other members of the Senior High School Science Subcommittee. This assistance in preparing these sections of the text to suit the requirements of Alberta schools has been most valuable. Thanks are also due to the many commercial organizations which provided illustrative material.

In conclusion we have not forgotten what we owe to the patience and understanding of our wives and families.

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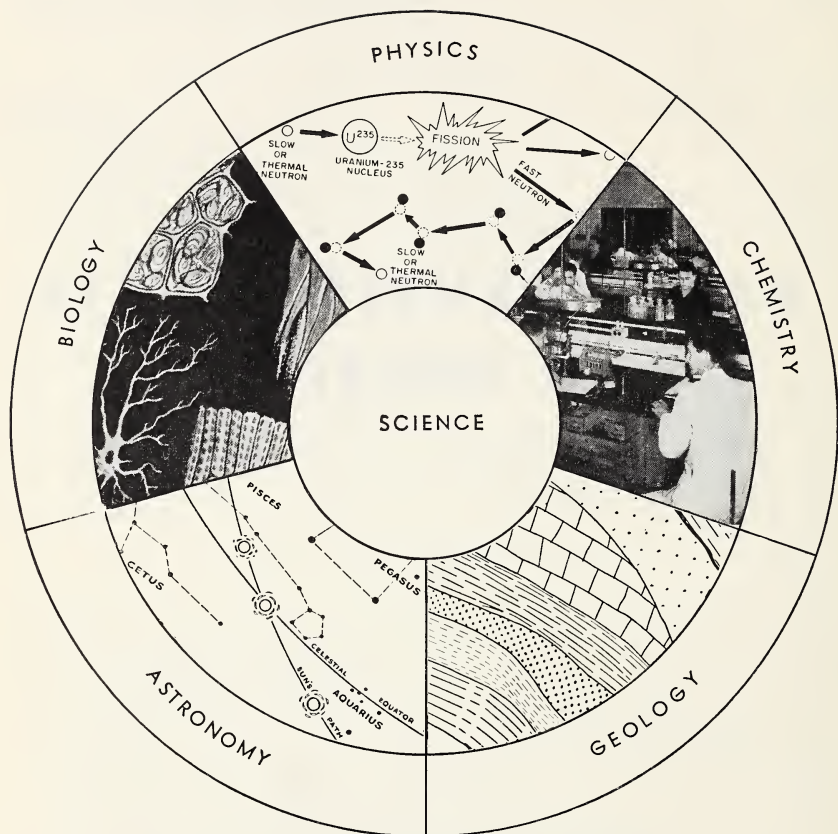
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**EARLY DEVELOPMENTS
IN PHYSICS**



THE MAJOR DIVISIONS OF SCIENCE

CHAPTER 1

INTRODUCTION

THE MEANING AND SCOPE OF PHYSICS

So wide is the subject's scope, and so numerous are its developments, that no single statement can convey fully what is meant by the word Physics—except, perhaps, the statement that this is the fundamental science, whose principles form the basis of such other sciences as Biology, Chemistry, Geology, and Astronomy. Its subject matter contains the principles that enable us to understand, as far as we do, the operation of the universe and everything within it, and, by telling us how the forces of nature act, it enables us to control them and put them to work in the service of man. Every time you turn on the taps for a bath, switch on the electric light, phone a friend, or one of the many other things which have come to seem the necessities as well as the luxuries of life, you will be in contact with devices whose invention was made possible by a knowledge of physical laws.

So vast a subject may seem unmanageable; and yet a division of it into all its possible parts would be equally bewildering. And so, for convenience, a division into several major sections, each

of which contains many separate subjects, is generally made. These sections are the subjects of the units of this book: Mechanics, Sound, Heat, Light, Electricity and Magnetism, and—in the chapter entitled Modern Developments in Physics—Nuclear Physics.

SOME EARLY DEVELOPMENTS

But before coming to these, let us look at our subject's past.

Theoretical physics may be said to have had its beginning when primitive man first speculated on the causes for the seasons, for day and night, and for the motions of the heavenly bodies, but practical physics did not begin until he invented such simple machines as the lever to lift weights and the wheel to move them. Slow as his progress was, it was from this time of his first applying his physical knowledge, in however fumbling and incomprehending a way, that he could date his emergence from his primitive existence towards what we think of as civilization.

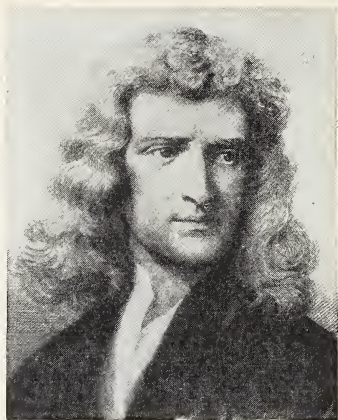
Society followed society, each progressing a little together with man's knowledge of physics. The famous civilizations of Egypt and Greece which, with the rapid expansion of knowledge that accompanied their eager enquiries into the mysteries of the universe, provide us with the first notable names in our story, those of the philosophers, or learned men, like Aristotle, Archimedes and Ptolemy. Archimedes, who is cele-

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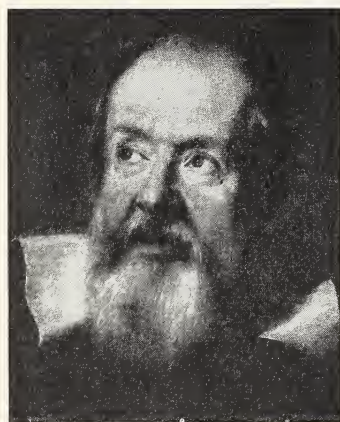
University of Toronto

Dr. William Gilbert (1540-1603)
Carried out many interesting experiments in magnetism and static electricity.



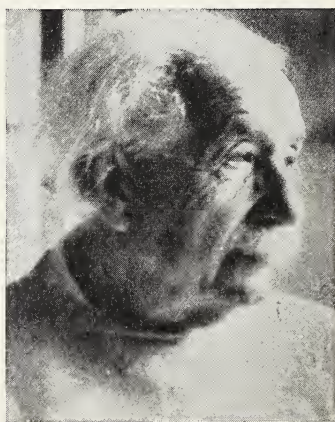
University of Toronto

Sir Isaac Newton (1642-1727)
English mathematician and physicist made many important scientific contributions.



University of Toronto

Galileo (1564-1642) Italian physicist, astronomer and mathematician.



Star Newspaper Service

Albert Einstein (1879-1955) American physicist, best known for his theory of relativity.

Fig. 1:1

INTRODUCTION

brated among other things for his laws of buoyancy, is the first man we know of who sought truth by experiment. Aristotle in Greece and Ptolemy in Egypt, on the other hand, relied solely on reasoning and logic for their explanations of natural phenomena and saw no reason for testing their speculations and theories experimentally.

After this first great awakening, little scientific progress was made for centuries and, in general, knowledge remained fixed at the theories of Aristotle. The genius of the Romans was exercised in conquest, government and law rather than in scientific enquiry. After them, during the Middle Ages when civilization was struggling for existence, it was left to the Arabs to try to preserve what scientific knowledge had been gained, by collecting as many of the writings of the Greeks and other peoples as possible. In north-western Europe, an Englishman, Roger Bacon (1214-1294), did indeed foresee many future scientific developments, but he was kept from making his theories known by fear of the Church which all this time fiercely opposed any scientific advance.

The shackles of the Church's opposition and the rigid adherence to Aristotle's scientific theories were not in fact broken until the sixteenth and seventeenth centuries when the great rebirth of intellectual activity which we call the Renaissance occurred. It is from this time that we date the beginning of modern experimental physics. Dr. Gilbert (1540-1603), Physician to Queen Elizabeth I, made the first experimental study of magnetism, and Galileo (1564-1642), experimentally established the laws of falling bodies. Sir Isaac Newton (1642-1727), who had perhaps one of the most brilliant and penetrating minds before the time of Einstein, developed the basic laws of mechanics, studied light and astronomy, and invented the very

useful branch of mathematics called calculus.

The century and more which followed Newton's death saw established all the main branches of physical science which were referred to in the first section, with the exception of nuclear physics. The work of Ampere, Volta, Ohm, and Faraday on electricity was so important that their names are still used to designate the units of measurement of electrical energy.

Most important for the nineteenth century, the period in which physical investigation reached a climax, was the work on heat which gave rise to the idea of the basic importance of energy as the source of all activity. All physical phenomena, it was found, represent transformations of energy, exchanges of energy, or the interaction of objects that possess energy. The general applicability of this concept of energy is what has led to the rather incomplete definition of physics as "the subject which deals with forces and forms of energy in our environment". Then, later in the nineteenth century, the study of energy reached its culmination, transforming the whole appearance of physics, when it was realized that energy is transmitted from place to place by a wave motion and that the various branches of physics are simply different energy phenomena transmitted in this manner. This realization of the wave motion of energy provides the beginner in physics with some hope at least of unity in a subject that appears to be greatly diversified.

On the practical side, the work of the nineteenth century laid the foundations, among other things, of almost all our modern means of communication, transportation and power production, both by electricity and atomic energy. In this last respect science seems to have provided a solution for the problems which its own developments were raising. Many

INTRODUCTION

of these developments made for new occupations, better working conditions, a higher level of health and a longer span of life, with a consequent increase in world population. The resulting larger demand for every kind of commodity necessitated such a rapid consumption of energy that the available reserves of the world began to dwindle rapidly and scientists had to explore, as they are still exploring, ways and means of avoiding disaster a few generations hence. As it happened, hope for the future was provided as early as 1905 by Dr. Albert Einstein (1879-1955) when he estimated the energy resources of the atom. Recently that hope has been translated into reality as physicists have learned to release and control this tremendous store of energy.

THE METHOD OF SCIENCE

Dr. Gilbert, the first great English exponent of the principles of magnetism, spoke defiantly of speculative scientists and traditionalists as "men of acute intelligence, without actual knowledge of facts who in the absence of experiment, easily slip and err". Thus were condemned most of the early philosophers and some later ones who supported such false beliefs as an earth-centred universe, the caloric theory of heat, and the two-fluid theory of electricity. Thus also was initiated the new method of scientific investigation, the Scientific Method, which has brought about the spectacular developments which mark our civilization, and of which it can be proud.

This method has been defined as the method of organized and critical common sense, a way of thinking that has been used by the successful farmer, craftsman, business or professional man from time immemorial. It is the method

used in all problem solving whether in science or daily life. Its steps are depicted in Fig. 1:2 and are as follows:

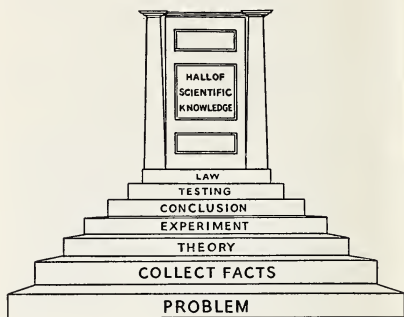
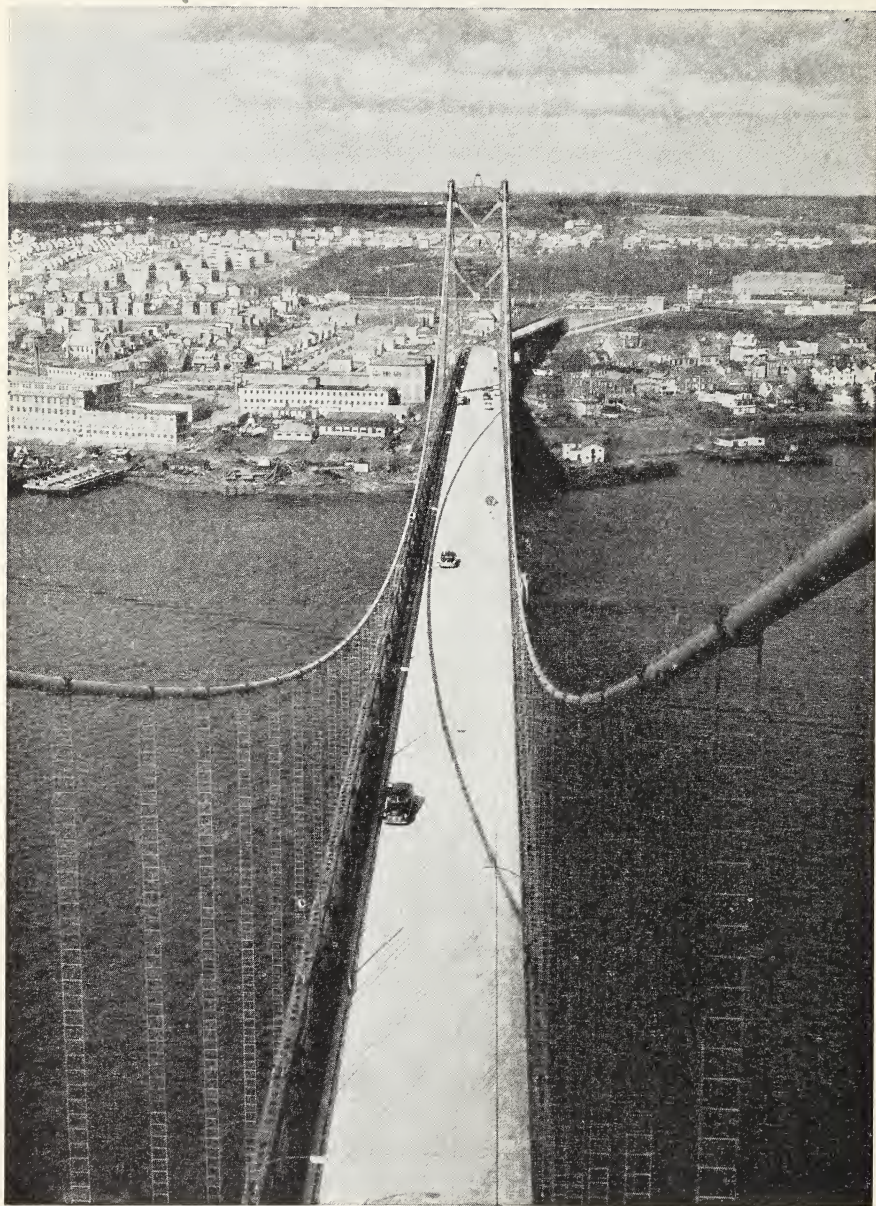


Fig. 1:2 Seven steps to knowledge.

- Step 1. There is a question or a problem without an answer.
- Step 2. The investigator collects all the facts he can about the problem.
- Step 3. In the light of what he now knows, he proposes a theory or possible explanation.
- Step 4. To test the theory, an experiment is devised, which, if successful, is repeated to determine whether or not a definite answer can be proposed.
- Step 5. The answer is enunciated.
- Step 6. This answer or conclusion is tested experimentally to find out whether it will always be true. If it is not always true, it is rejected and a fresh start is made.
- Step 7. If the answer is found always to hold true, it becomes a law in the vast body of scientific knowledge and, as such, it may be used to help make further discoveries.

UNIT I

MECHANICS



E. G. L. Wetmore

The Angus L. Macdonald Bridge, Nova Scotia. What Laws of Mechanics Would Apply Here?

1 : 1 SYSTEMS OF MEASUREMENT

As civilization developed and life became more complex, with man planting crops, trading goods or purchasing property, it became essential for him to have some means of measuring length, area, volume, mass and time. The daily

movements of the earth, with the resulting apparent motion of the sun and stars, provided a ready-made device for measuring time, but the measurement of the other dimensions could not be managed so naturally.

Man's first systems for measuring them, however, were, though imprecise, very convenient. Measurements of length were based upon parts of the human body (Fig. 2:1). Measurements of weight were often made by using crude scales in which the object to be weighed was balanced against stones or seeds of

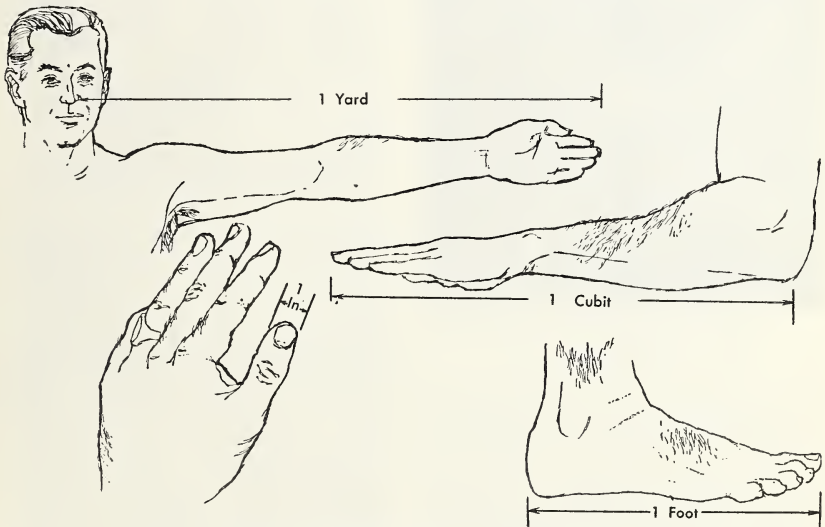


Fig. 2:1 Primitive Measuring Devices.

grain. The convenience of these units is obvious. In measuring a board a man would not have to hunt for a ruler, but would have used his hand or arm. However, in one fundamental respect, these early units were unsatisfactory. They were not standard or uniform.

Moreover, with the beginnings of science and the growth of technology from the invention of the first simple machines, as we have seen, the need for definite and accurate systems of measurement became imperative. Since the aim of science is to describe the facts of experience as simply, as completely, and as accurately as possible, measurement is the very basis of it. Physics is that



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Fig. 2:2 Scientist at work.

branch of science which is specially concerned with the means of measurement—which is why physics is called an “exact science”, and why the other divisions of science depend, in varying degrees, on its special techniques.

What are needed, then, are standard

units of measurement, units, that is, which are generally acceptable, and preferably units which can be easily and accurately reproduced at any time. Yet,

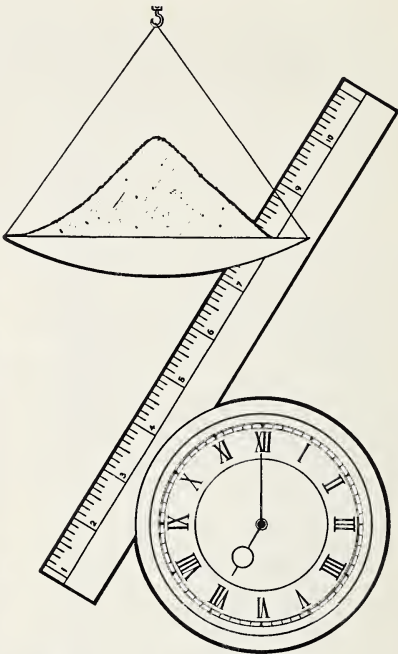


Fig. 2:3 The Three Measurable Magnitudes—Length, Mass and Time.

to define new standards for every type of quantity to be measured would lead to a large collection of unrelated constants.

In order to simplify the scheme of measurement, all units have been brought into relation to three measurable magnitudes, length, mass, and time, which form a basis for all measurements.

SYSTEM	LENGTH	MASS	TIME
<i>English</i>	<i>Foot</i>	<i>Pound</i>	<i>Second</i>
<i>Metric</i>	<i>Centi- metre</i>	<i>Gram</i>	<i>Second</i>

There are two systems of units in common use, the British, or foot-pound-second (F.P.S.) system, and the Metric, or centimetre-gram-second (C.G.S.) system. The history of the development of these systems of measurement is very interesting, but unfortunately cannot be given here. The interested student can find it in any good reference encyclopedia.

All the world except the two great English-speaking groups, the British Commonwealth of Nations, and the United States of America, has adopted the metric system of measurement. The metric system is extremely simple, being nothing more nor less than the application of the decimal number system to measurements. Measurements of length and mass begin with a basic unit, the next larger unit being ten times as large, the next smaller unit one-tenth as large, and so on. To convert from one unit to another simply consists in shifting the decimal point one place to the left or right, e.g., 123 metres = 12.3 dekametres, or 1230 decimetres. The relationship of each larger or smaller unit to the basic unit is shown by the prefix to its name. (See the table of prefixes above.) Thus a centimetre is one-hundredth of a metre, (centi = $1/100$), while a kilometre is one thousand metres (kilo = 1000). Moreover, the metric system has continuity in that the unit of mass is related to the unit of length. (See definition of "gram" in the next section.) The British system of weights and measures is much more cumbersome and difficult, both because of the heterogeneous groups of multipliers used, and because of the unrelated units of mass and length.

Since the metric system has such decided advantages over the British system, it is used almost exclusively in the scientific field. While this system is legal in both the United States of America

and the British Commonwealth of Nations, its common adoption in these countries is prevented in large measure

TABLE OF PREFIXES	
<i>Latin</i>	<i>Greek</i>
Milli = $1/1000$	Deka = 10
Centi = $1/100$	Hecto = 100
Deci = $1/10$	Kilo = 1000

by habitual use of the older system, and by the large amount of industrial machinery already geared to the British system. The student of science is well-advised to master the metric system thoroughly since a working knowledge of it is essential to a proper understanding of many scientific principles that follow.

I : 2 UNITS OF MEASUREMENT

(a) Length

The British system of units is based on the standard yard, which is the distance at 62°F. between the centres of two fine lines engraved on gold studs sunk in a bronze bar. It is kept in the Standards Office in London, England, and a copy of it is preserved in the Department of Inland Revenue at Ottawa. The metric unit of length is the **metre** (Fig. 2:4), which is the distance at 0°C. between the centres of two lines traced on a platinum-iridium bar, kept at the International Bureau of Weights and Measures, in Sèvres, near Paris. A copy of it is also kept in Ottawa.

TABLE OF LINEAR MEASURE

British Units

12	inches (in.)	= 1 foot (ft.)
3	feet	= 1 yard (yd.)
	$5\frac{1}{2}$ yards	= 1 rod (rd.)
320	rods	= 1 mile (mi.)

Metric Units

10	millimetres (mm.)	= 1 centimetre (cm.)
10	centimetres	= 1 decimetre (dm.)

10 decimetres	= 1 metre (m.)
10 metres	= 1 dekametre
10 dekametres	= 1 hectometre
10 hectometres	= 1 kilometre (km.)
1 inch	= 2.54 centimetres

In the measurement of area and volume, the units used are derived from linear units. Since a surface has two

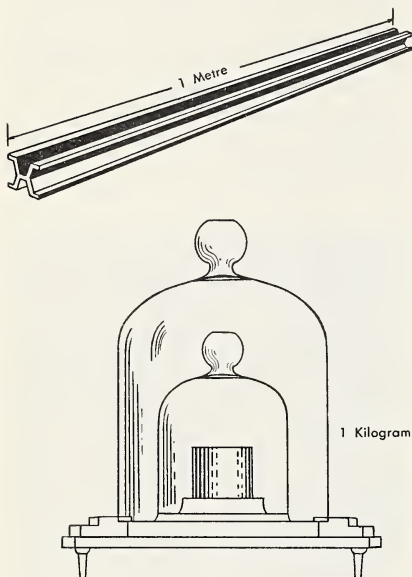


Fig. 2:4 Standard Metric Units—The Metre, The Kilogram.

dimensions, length and width, the units of area are expressed in square measure. Since an object has three dimensions, length, width and height, the units of volume are cubic measure. From the previous tables of linear measure, the student should be able to prepare tables of square measure and of cubic measure in both British and metric units.

One unit for measuring volume, the litre, deserves emphasis above the others as it is frequently used in scientific work.

For practical purposes it has the same volume as a cubic decimetre or 1000 cubic centimetres.

1 litre	= 1 cubic decimetre (cu. dm.)
	= 1000 cubic centimetres (c.c.)
	= 1000 millilitres (ml.)
	= 1.76 pints.

Note. The ml. and c.c. may be used interchangeably for our purposes, even though the two are not absolutely identical.

(b) Mass

The unit of mass in the British system is the **pound**. The standard pound is the quantity of matter in a cylinder of pure platinum about 1.35 inches high and 1.15 inches in diameter, kept in the Bureau of Standards in London, England. In the metric system, the unit of mass is the **kilogram** (Fig. 2:4), which is the mass of a piece of platinum-iridium kept at Sèvres, France. Originally it was intended to be the mass of 1000 cubic centimetres (1 litre) of water at 4°C. and at standard atmospheric pressure (i.e., 760 mm. of mercury). The gram is one-thousandth part of a kilogram, and is the mass of one cubic centimetre of water at 4°C. and at standard atmospheric pressure.

COMMON UNITS OF MASS

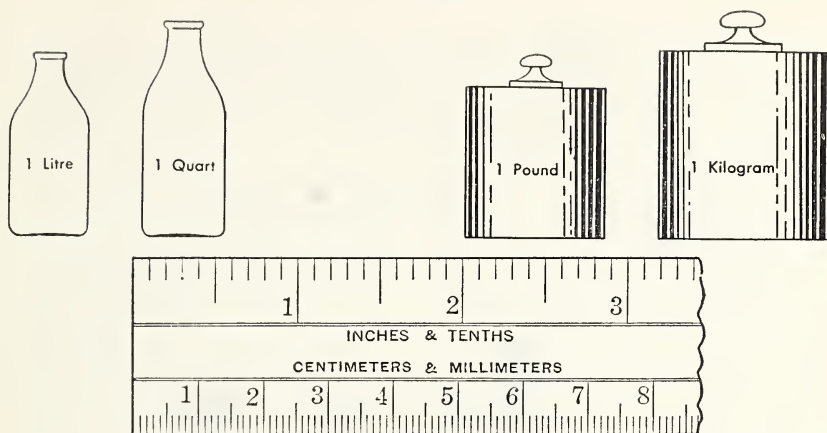
British Units

16 ounces (oz.)	= 1 pound (lb.)
2000 pounds	= 1 ton

Metric Units

10 milligrams (mg.)	= 1 centigram (cg.)
10 centigrams	= 1 decigram (dg.)
10 decigrams	= 1 gram (gm.)
10 grams	= 1 dekagram
10 dekagrams	= 1 hectogram
10 hectograms	= 1 kilogram (kg.)
1 kilogram	= 2.2 pounds (approx.)

It should be recalled that although the units for measuring mass and weight are the same, mass and weight are dif-



1 in. = 2.54 cm. 1 kg. = 2.2 lb. 1 Litre = 1.76 pints.

Fig. 2:5 Comparison of British and Metric Units.

ferent. Mass is the quantity of matter in an object and is always constant. Weight is the pull of gravity upon an object and varies with the distance of the object from the earth's centre.

(c) Time

The second is the unit universally used in reckoning time. Like day and night and the seasons, it is determined by the earth's motion. The average time between successive passages of the sun across a meridian is called the mean solar day, and the second is $1/86,400$ part of it. In other words, the second is $1/86,400$ of the time which the earth takes to make one complete rotation on its axis.

I:3 CALCULATIONS BASED ON MEASUREMENTS

(a) Accuracy of Measurement

In the experiments at the end of this unit, chapter 6, and throughout the book, you will have opportunities to make measurements and use some of the units mentioned in the previous

section. Measurement seems a very accurate operation indeed, but there is a limit to the degree of accuracy that is possible. If a farmer has five hundred baskets of fruit, this is an exact number. When he sells them for fifty cents each he will receive exactly two hundred and fifty dollars, another exact number. In this and all other similar operations involving a number of finite objects, you are dealing with exact numbers.

If, however, you measure the length of your living-room and say that it is fifteen feet long, it is likely to be a little longer or shorter than this. In the same way a door that is thirty inches wide may measure a little more or a little less than this. The limit of accuracy is governed to a large extent by the type of measuring instrument that is used and the care exercised in using it. Figure 2:6 shows a number of instruments used for making measurements. Because all measuring devices have limitations, it follows that all measurements are approximate and calculations based on such measurements, although the

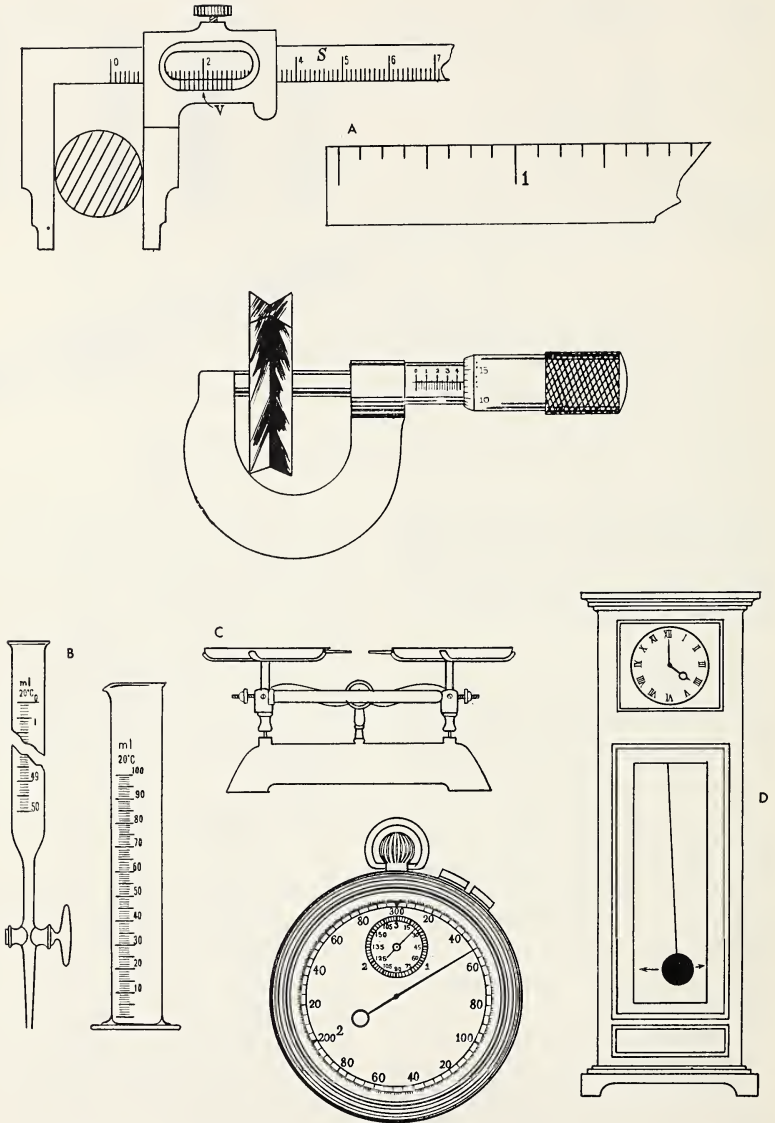


Fig. 2:6 Instruments for Measuring: A Length—Ruler, Calipers, Micrometer; B Volume—Burette, Graduated Cylinder; C Mass—Equal Arm Balance; D Time—Pendulum, Stop-Watch.

mathematical operations are done correctly, give numbers as answers that are not quite perfect. Thus numbers that are derived by measurement are called **approximate numbers**.

(b) Calculations

The aim in calculations is to arrive at an answer that is as accurate as possible but that, at the same time, does not indicate more accuracy than that of the least accurate measuring instrument employed. Thus, if the dimensions of a rectangle are 7.54 cm. by 3.81 cm., the proper area is 28.7 sq. cm., not 28.7274 sq. cm. The latter number expresses measurement with greater accuracy than is possible with the means at our disposal. The reasons will be apparent after studying later paragraphs (page 15).

(c) Approximate Numbers

In all measurement, you must first decide what will be the **limits of accuracy**

of your work and then realize that a **possible error** exists in the result. In order to make this small, the possible error is not permitted to exceed one-half of the smallest unit employed in the operation. Thus, in the previous examples, if 1/8 inch were the smallest unit on the measuring instrument used, a possible error of 1/16 inch more or less is found in the answer. Accordingly the length of the room in part (a) would be between 14 feet, 15/16 inch and 15 feet, 1/16 inch and the width of the door would be between 29 15/16 and 30 1/16 inches. Similarly, if the present room temperature is given as 21.5°C., and the thermometer is marked off into 0.1 degree units, the possible error will be .05 centigrade degrees and the actual reading may be between 21.45°C. and 21.55°C. The reading 21.5°C. represents the temperature as accurately as the means of measurement at our disposal will permit. Other examples follow:

<i>Measurement</i>		<i>Limits of Accuracy</i>				
55.3 cm.	From 55.25 cm.	up to but not including	55.35 cm.			
719 ft.	" 718.5 ft.	" " " "	" 719.5 ft.			
19.0 ft.	" 18.95 ft.	" " " "	" 19.05 ft.			
0.0032 in.	" 0.00315 in.	" " " "	" 0.00325 in.			

To allay the fear that naturally arises over the presence of this possible error, let us calculate what per cent of the whole it represents. The percentage error is possible error divided by the accepted number times 100. Using the first measurement in the preceding table we get:

The percentage error =

$$\begin{aligned} & \frac{55.3 - 55.25}{55.3} \times 100 \text{ or } \frac{55.3 - 55.35}{55.3} \times 100 \\ & = + \frac{.05}{55.3} \times 100 \text{ or } - \frac{.05}{55.3} \times 100 \\ & = + .09\% \text{ or } - .09\% \end{aligned}$$

From this, we see that approximate numbers contain an extremely small error. The more precise the measuring device is, the smaller the unit of measurement will be. The smaller the unit of measurement is, the smaller the possible error will be.

(d) How to Deal with Approximate Numbers

1. Significant Digits

When performing a measurement, only those numbers in the measurement that are certain, like the 15 feet, 30 inches, 21.5°C. of previous paragraphs, are recorded. The digits in these numbers

are called the **significant digits** in the result, there being two in the first two numbers above, and three in the third. Mathematicians have laid down certain rules to guide us in working with them. They are as follows:

1. All the digits from 1 to 9 including any zeros between them or after them are significant digits.
2. The position of the decimal is disregarded in determining the number of significant digits.
3. The zeros preceding the first digit are not significant.

SIGNIFICANT DIGITS IN NUMBERS

Number	Significant Digits
604	3
60.4	3
6.04	3
0.604	3
0.0604	3
0.06004	4
604.0	4
60.40	4

2. Representing Significant Digits in Large Numbers

Where a number like 600 is correct to one significant digit, it should be written as 6×10^2 . To express it as 600 indicates three significant digits. Similarly, the distance from the earth to the sun is correct to only two significant digits and should be written 93×10^6 rather than 93,000,000 miles.

3. Rounding off Approximate Numbers

A number like the value of pi (π), 3.14159, is correct to 6 significant digits. It may be made consistent with measurements having fewer than six significant digits by the process of **rounding-off**. This means dropping the necessary number of digits off the end of a number and adding one to the last remaining digit if the next digit was five or more.

Examples

Rounding-off	Accuracy
3.14159	6 significant digits
3.142	4 " "
3.1	2 " "

4. Calculations With Significant Digits

How to carry out mathematical operations with approximate numbers is indicated by the following rules:

1. Addition and Subtraction

In operations involving addition and subtraction of approximate numbers of which the least precise has N places of decimals, round off the other numbers where possible to $N + 1$ places and the answer to N places.

2. Multiplication and Division

In operations involving multiplication and division of approximate numbers of which the least accurate has N significant digits, round off the others where possible to $N + 1$ digits and the answer to N digits.

Examples

	Method	Result
1. Add	2.0149	
	3.02864	
	1.239	
	1.97	
	Round off all to three decimals where possible.	2.015 3.029 1.239
	Round off answer to 2 decimals.	1.97

Total = 8.253

Proper answer = 8.25

	<i>Method</i>	<i>Result</i>
2. Subtract 21.347 from 32.5	As for addition	32.5 21.35
		Difference = 11.15 Proper answer = 11.2
3. Multiply 2.1 by 2.56 and by 9.547	Round off all numbers to 3 significant digits. Keep 3 significant digits in all partial products. Round off answer to 2 significant digits.	$2.1 \times 2.56 = 5.376$ Proper product = 5.38 $5.38 \times 9.55 = 51.3790$ Proper answer = 51.
4. Divide 96.568 by 7.02	As for multiplication	$\frac{96.57}{7.02} = 13.75$ Quotient = 13.75 Proper answer = 13.8

On page 13 we multiplied 7.54 by 3.81, getting 28.7274 for an answer. However, as the multiplier and multiplicand are correct to three significant digits only, 28.7 is the proper answer. You may wonder about the usefulness of

the above material, but be assured that the method is used daily by scientists and mathematicians whose work has contributed so much to each modern development and invention.

(e) Applying Approximate Numbers in Elementary Physics

The diameter of a cylindrical solid is 2.50 cm. and it is 10.04 cm. long. ($\pi = 3.1416$). Its mass is 280.76 gm. Calculate its density.

$$\text{Radius} = 1.25 \text{ cm.}$$

$$\text{Length} = 10.04 \text{ cm.}$$

$$\pi = 3.1416 = 3.142$$

$$\begin{aligned} \text{Area of the end of the cylinder} &= \pi R^2 \\ &= 3.142 \times 1.25 \times 1.25 \\ &= 4.910 \text{ sq. cm.} \end{aligned}$$

$$\begin{aligned} \text{Volume of the cylinder} &= \text{area of end} \times \text{length} \\ &= 4.910 \times 10.04 \\ &= 49.30 \text{ c.c.} \end{aligned}$$

$$\text{The mass given} = 280.76 \text{ gm.}$$

$$\text{The proper mass} = 280.8 \text{ gm.}$$

$$\therefore 49.30 \text{ c.c. of solid weigh } 280.8 \text{ gm.}$$

$$\begin{aligned} \therefore 1 \text{ c.c. of solid weighs } &\frac{280.8}{49.30} \\ &= 5.695 \text{ gm.} \end{aligned}$$

$$\therefore \text{The density} = 5.70 \text{ gm. per c.c.}$$

I : 4

QUESTIONS

A

1. (a) Why is measurement necessary?
(b) Why was it necessary to establish standard units?
2. (a) Name the two systems of measurement and name the fundamental units for each.
(b) What advantages has the metric system over the British system of measurement?
(c) Why is the British system still used in a few countries?
3. (a) What apparatus is commonly used in the laboratory for the measurement of (i) length (ii) mass (iii) time?
(b) Suggest other pieces of apparatus that could be used to measure these fundamental units more accurately.
4. (a) State the number of millimetres, centimetres and decimetres in 1 metre. How many metres are there in 1 kilometre?
(b) Using the above units construct tables of (i) square measure (ii) cubic measure.
(c) Define: litre, millilitre.
5. (a) Distinguish between the mass and weight of an object.
(b) State the number of milligrams, centigrams, decigrams, and grams in 1 kilogram.
6. (a) Why was the apparent motion of the sun adopted as the basis for reckoning time?
(b) Define: mean solar day, second.
7. (a) Distinguish between exact and approximate numbers. Give an example of each.
(b) What gives rise to approximate numbers? Why?
8. (a) What do you mean by possible error?
(b) How do you calculate percentage error?
9. (a) What is meant by significant digits?
(b) State the number of significant digits in each of: 32060, 36.060, 0.32060, .032060, 3×10^3 , 3.56×10^5 .
10. (a) What is meant by rounding off a number?
(b) Round off the following to two significant digits: 36.7, 34.32, 37.495.
11. (a) State the rules for carrying out the following mathematical operations with approximate numbers: (i) addition and subtraction. (ii) multiplication and division.
(b) Do the following:
(i) $10.3575 + 9.75 - 8.65248$.
(ii) $7.935 \times 2.4248 \div 2.3$.

B

1. (a) Express in cm.: 15.2 m., 38 mm., 6 m. 5 cm. 4 mm.
(b) Express in sq. cm.: 3 sq. m., 236 sq. mm., 6 sq. m. 5 sq. cm. 44 sq. mm.
(c) Express in c.c.: 2.5 cu. m., 2300 cu. mm., 6 cu. m. 50 c.c. 465 cu. mm.
2. (a) Determine the number of inches in 950 mm., 40 cm., 10 dm.
(b) Determine the number of (i) cm. in 1 foot, (ii) km. in 1 mile.
(c) Which is the greater distance, 100 yd. or 100 metres? Express the difference in (i) ft. (ii) cm.
(d) An object is travelling at the rate of 40 miles per hour. Calculate the rate in (i) ft. per sec. (ii) metres per sec. (iii) kilometres per hour.
3. A tank is 50 cm. long, 3 dm. wide, and 150 mm. high.
(a) Calculate the area of a cover

- for the tank (i) in sq. cm. (ii) in sq. dm.
- (b) Calculate the volume of the tank, and express in (i) c.c. (ii) cu. dm. (iii) litres.
4. (a) What mass of water will the above tank hold (1 c.c. of water weighs 1 gm.)? Express this mass in gm., mg., cg., dg., kg.
- (b) Calculate the number of (i) grams in an ounce (ii) kilograms in a ton?
- (c) Calculate your own weight in kilograms.
5. A beaker is 20 cm. high and has a diameter of 14 cm. Calculate its volume in (i) litres (ii) millilitres (iii) pints.
6. Using proper "rounding-off" techniques, make the following calculations:
- (a) Add $9.75 + 10.357 + 76.92 + 5.674$.
- (b) Subtract
- (i) 10.357
- (ii) 5.674
- (iii) 9.75
- from 76.92.
- (c) Multiply
- (i) $2.6 \times 7.93 \times 1.732$.
- (ii) $77.5 \times 1.4142 \times .0032$.
- (iii) $46 \times 23.55 \times 0.25$.
- (d) Divide
- (i) 154 by .11.
- (ii) 9.5 by 19.03.
- (iii) 134.5 by 15.

CHAPTER 3

DENSITY AND SPECIFIC GRAVITY

I : 5 MEANING OF DENSITY

In ordinary conversation we often say that one substance is "heavier" than another, e.g., iron is "heavier" than aluminum. Obviously we cannot mean that any given piece of iron is heavier than every piece of aluminum, but rather that for pieces of equal size, the iron would be the heavier. In science we use the term density to express the physical difference implied in the above everyday statement, that is, we say that iron has a greater density than aluminum. **Density is defined as the mass of a unit volume of a substance.** The method of determining density is described in chapter 6, experiments 1, 2 and 3.

In stating densities the numerical measure must always be accompanied by suitable units, e.g., gm. per c.c., lb. per cu. ft., etc., according to the units in which the mass and volume of the substance have been measured. It should further be noted that the numerical value of the density of any given substance will depend on the system of units used. Thus, since one gram of water (at its maximum density) occupies a volume of one cubic centimetre (Sec. I:2), the density of water in the

C.G.S. system of units is 1 gm. per c.c. In the F.P.S. system, however, a cu. ft. of water is found to weigh 62.5 lb. (approx.), and hence the density of water in this system of units will be expressed as 62.5 lb. per cu. ft. Densities (in gm. per c.c.) of various substances are given in the table on page 21.

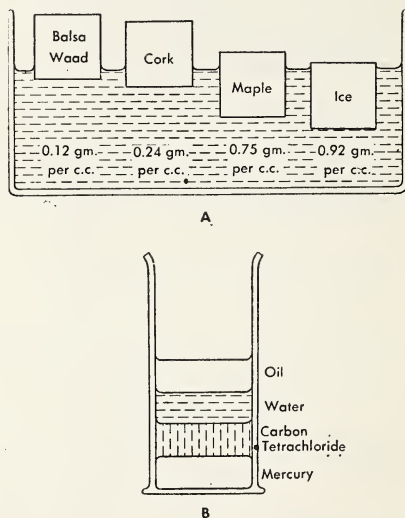
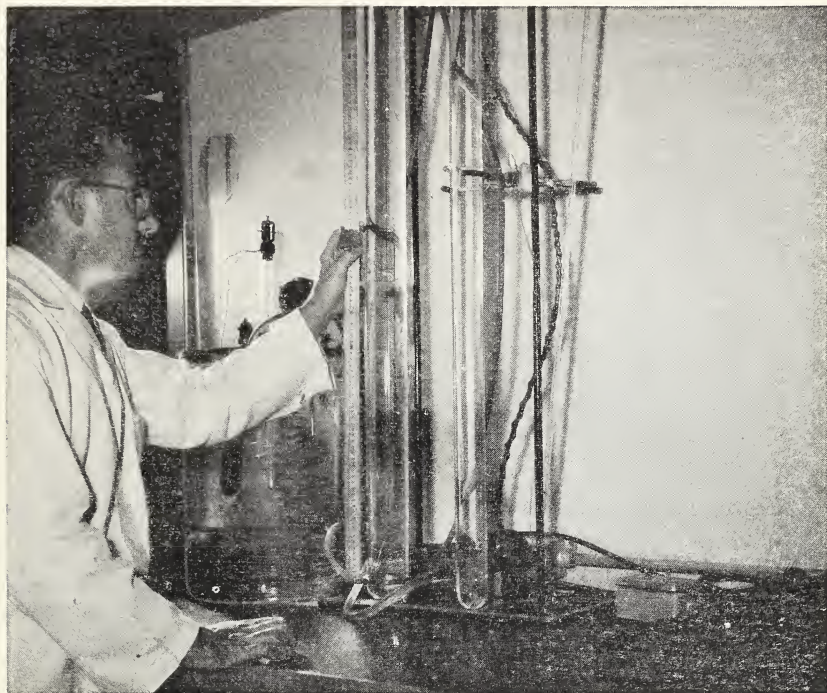


Fig. 3:1 Relative Densities of
A—Solids, B—Liquids.

To find the corresponding densities in lb. per cu. ft. the numerical values must be multiplied by 62.5.



Canadian Industries Ltd.

Research Scientist Determining the Density of a Substance by Comparison with Standard Density Floats Suspended in a Solution of Known Density.

We have previously defined mass as the quantity of matter in a body. According to modern theory, matter is comprised of molecules, the molecules of any given substance being identical to each other. Hence, differences in density between various substances (Fig. 3:1), are due to the relative masses of their molecules as well as to their spatial arrangement. Variations in the density of a given substance are due to changes which vary the closeness of packing of the molecules.

I : 6 DENSITY OF WATER

It is frequently said that the density of water is 1 gm. per c.c. However, liquids, like solids and gases, expand when heated and contract when cooled with no change whatever in mass. They therefore have different densities at different temperatures.

Careful experiments to show changes in density of water with changes in temperature can be carried out with the aid of the dilatometer shown in Fig. 3:2. If this instrument, filled with water,

is placed in a water bath with a thermometer, and ice slowly added, the volume change can be observed on the

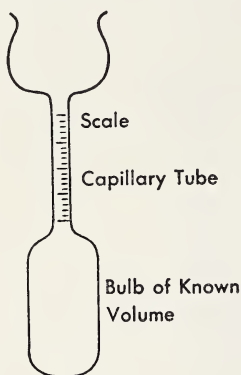


Fig. 3:2 A Dilatometer.

scale, for changes of temperature down to 0°C . The water contracts, i.e., its density increases, until a temperature of

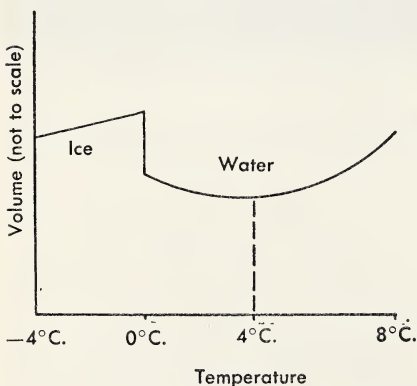


Fig. 3:3 Graph to Show the Effect of Changes of Temperature on the Density of Water.

4°C . is reached. After that, further cooling makes it expand, i.e., its density decreases again. The temperature at

which the volume is smallest is the temperature at which the density is the greatest, namely 4°C . We say that water has its maximum density at 4°C . It is at this temperature that 1 cubic centimetre of water has the mass of 1 gram. The changes mentioned above are shown graphically in Fig. 3:3. (Most liquids show a gradual increase in density as the temperature goes down.)

This fact, together with the fact that there is a sudden expansion as water freezes at 0°C . (evidenced by those burst pipes in winter!) is of profound importance in nature. With wintry conditions the coldest layers of a pond or lake are those at the surface, and when these layers freeze the ice so formed remains on the surface because its density is less than that of the water beneath it. Without this unusual behaviour of water the pond would freeze solid from the bottom upwards, greatly to the detriment of all life and to aquatic life in particular.

1 : 7 MEANING OF SPECIFIC GRAVITY

For many purposes, instead of density, it is found more convenient to use the density of a substance relative to that of water. The relationship so obtained is called the **specific gravity** of the substance. It may be calculated in the following way:

$$\text{S.G.} = \frac{\text{density of the substance}}{\text{density of water}}$$

$$\text{S.G.} = \frac{\text{mass of unit volume of the substance}}{\text{mass of unit volume of water}}$$

$$\text{S.G.} = \frac{\text{mass of any volume of the substance}}{\text{mass of an equal volume of water}}$$

Thus specific gravity is a ratio and no units are required. It is simply a num-

ber stating how many times as heavy as water, bulk for bulk, the substance is. Further, it must be evident that the number giving the specific gravity of a substance will be the same whatever the units in which the masses are measured, (Chap. 6, Exp. 4, 5, 6).

In the C.G.S. system the density of water is 1 gm. per ml., and thus in this system, density and specific gravity are numerically equal. The two terms are

not interchangeable, however, although frequently, but wrongly, so used.

I : 8 DENSITY OR SPECIFIC GRAVITY OF VARIOUS SUBSTANCES

The density or specific gravity of solids, liquids and gases is a property that helps us to identify them. Some of these you will have determined experimentally while others will be found in the accompanying table of specific gravities.

TABLE OF APPROXIMATE SPECIFIC GRAVITIES

Metals

Magnesium	1.74	Silver	10.5
Aluminum	2.70	Lead	11.4
Zinc	7.15	Mercury	13.6
Tin	7.30	Gold	19.3
Iron (pure)	7.85	Platinum	21.5
Copper	8.90		

Alloys

Steel	7.0-7.7	Brass	8.4-8.7
Iron (cast)	7.1-7.7	Bronze	8.7-8.9

Miscellaneous Solids

Cork	0.24	Sand	2.6
Ice (0°C.)	0.92	Pine	0.6
Salt	2.2	Oak	0.8

Liquids

Gasoline	0.70	Carbon tetrachloride	1.60
Alcohol	0.79	Sea-water	1.01-1.05
Turpentine	0.87	Conc. sulphuric acid	1.83

Gases (at S.T.P.)

Hydrogen	0.00009	Oxygen	0.00143
Helium	0.00018	Carbon dioxide	0.00198
Air	0.00129	Chlorine	0.00322

Gases, being so light, generally have their densities expressed in grams per litre, instead of grams per cubic centimetre. Also, air or hydrogen (preferably the latter) is used as the standard, rather than water, for purposes of comparison.

1 : 9

QUESTIONS

A

1. (a) Define density and state what two measurements must be made in order to calculate the density of an object.
(b) Calculate the density of a piece of aluminum whose volume is 150 c.c. and whose mass is 405 gm.
2. (a) What effect does an increase in temperature have on the density of most substances? Why?
(b) In what respect may water be said to be an unusual liquid?
(c) Explain why this unusual behaviour of water is important to life.
(d) Why does it require a much longer and more severe period of cold weather to cause a layer of ice to form on deep bodies of water than to form on shallow bodies?
3. (a) Define specific gravity and state clearly what is needed to find the specific gravity of an object.
(b) Calculate the specific gravity of a substance whose volume is 20 c.c. and whose mass is 160 gm.
4. (a) Distinguish between density and specific gravity.
(b) What relationship exists between the specific gravity of a substance and its density?
(c) What is the specific gravity of the aluminum in 1. (b)?
5. Find the mass of 20 cu. ft. of material whose density is 3.2 lb./cu. ft.
6. Find the volume of an object whose mass is 42.7 lb. and whose density is 2.10 lb./cu. ft.
7. Find the specific gravity of a substance whose mass is 148.5 gm. and whose volume is 30.5 c.c.
8. The specific gravity of a substance is 1.85. What volume of it weighs 100 gm.?
9. Find the mass of 0.5 litres of a liquid whose specific gravity is 1.6.
10. Find the specific gravity of a substance whose mass is 3.2 lb. and whose volume is .75 cu. ft. (Density of water is 62.5 lb. per cu. ft.)
11. The specific gravity of a substance is 2.7. What volume of it will weigh 100 lb.?
12. Find the mass of 3.2 cu. ft. of material whose specific gravity is 8.9.
13. An irregular object has a mass of 72.6 gm. On placing it in water in a graduated cylinder the level rises from 12.0 ml. to 21.5 ml. Calculate its density.
14. A specific gravity bottle weighed 24.20 gm. when empty, 67.81 gm. when filled with turpentine and 74.20 gm. when filled with distilled water. What is the specific gravity of the turpentine?
15. A flask weighs 8.8 gm. when empty, 33.6 gm. when filled with water and 28.6 gm. when filled with alcohol. Find the specific gravity of the alcohol.

B

1. Calculate the density of a rectangular solid 25 cm. long, 15 cm. wide, 3 cm. thick, whose mass is 5625 gm.
2. Find the mass of 75 ml. of a liquid whose density is 0.70 gm./ml.
3. Find the volume of an object whose mass is 750 gm. and whose density is 2.80 gm./c.c.
4. Find the density of water if 15 cu. ft. weigh 937.5 lb.
5. The density of a salt solution is 1.20 gm. per ml. If a flask weighs 12.6 gm. when empty and 62.8 gm. when filled with water, how much will it weigh when filled with the solution?
17. The composition of brass is 75% copper and 25% zinc by volume. Calculate its density.
18. An alloy of tin and lead has a specific gravity of 10.6. Calculate the proportion of tin present in the alloy (a) by volume (b) by weight.

19. A piece of wax whose real specific gravity is 0.96 has an apparent specific gravity of 0.92 owing to a bubble of air being enclosed in it. The volume of the whole is 10.0 c.c. Find the volume of the air enclosed, assuming the weight of the air to be negligible.

20. A piece of metal 11.2 cm. long, 4.5 cm. wide and 1 mm. thick, has a mass of 30.2 gm. Find its density.

21. Calculate the density of a cylinder whose length is 5.2 cm., diameter is 12 mm., and whose mass is 58 gm.

22. Calculate the density of a sphere whose radius is 1.4 cm. and whose mass is 100 gm.

23. A cube of ice whose side is 4 cm. is allowed to melt. The volume of the water is found to be 58.2 ml. Find the density of ice.

24. Four solutions of salt, of densities 1.12, 1.17, 1.19 and 1.20 gm. per c.c., are mixed together in the proportion 1:2:3:4 by volume. Find the density of the mixture.

1 : 10 INTRODUCTION TO BUOYANCY

We are all familiar with the fact that things seem lighter under water. Those of us who have helped to build a dock know that a large stone which can only be raised with difficulty when out of the water may be raised quite easily when under water. Similarly, we find that

force will be apparent after a consideration of the forces that water exerts on an object immersed in it (Fig. 4 : 1). The water exerts a downward pressure upon the top surface of the object, and an upward pressure upon the bottom. Because the bottom of the object is deeper in the liquid than is the top, and because pressure increases with depth, the upward pressure upon the bottom surface will exceed the downward pressure upon the top surface. There will, therefore, be a net upward pressure upon the block. It is this upward force that accounts for the apparent lightness of an object when immersed in the water. The same principle applies to all bodies immersed in any liquid or gas.

Archimedes (287-212 B.C.), a Greek mathematician and inventor, was the first to study the buoyancy of liquids and to enunciate an important principle connected therewith. The story is told that Hiero, king of Syracuse, had sent his jeweller a known mass of gold to be made into a new crown. When the crown was delivered and tested it was found to have the right weight, but there was a suspicion that some silver had been substituted for gold in the interior of the crown. Consequently Archimedes was commissioned to determine whether or not the crown was pure gold, at the same time being instructed not to mar the crown in any way.

Archimedes puzzled over this problem at great length. All that he had to work

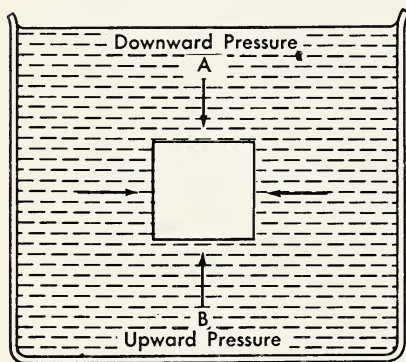


Fig. 4:1 Explanation of Buoyancy.

an anchor becomes heavier on emerging from the water. In general then, bodies immersed in water (or in any fluid) appear to lose some of their weight. This is, of course, due to the fluid exerting a buoyant force or lift on them.

The reason why fluids exert a buoyant

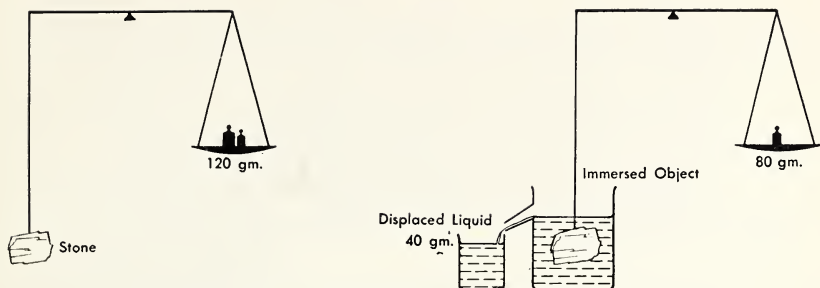


Fig. 4:2 Archimedes' Principle.

with was the well-known fact that an object is easier to lift when immersed in water than when on land.

One day as he hopped into his bath, which had been filled brimful of water, he caused a considerable quantity to overflow onto the brick floor, and he was suddenly struck by the idea that the weight he lost on submerging was equal to that of the water which overflowed. He was so excited by this discovery, so the story goes, that he ran home unclothed shouting, "*Eureka! Eureka!*" ("I have found it! I have found it!")

As you study the principle that Archimedes enunciated, see if you can suggest the experiment that Archimedes probably performed to determine whether or not the crown was pure gold.

I : 11 ARCHIMEDES' PRINCIPLE

The experiment to demonstrate Archi-

medes' Principle (Chap. 6, Exp. 7, 8) should be studied carefully in conjunction with the following statements:

1. When a body is immersed in a liquid it displaces some of the liquid to make room for itself. Note that the volume of the liquid displaced is equal to the volume of the object.
2. The body is buoyed up by the liquid and therefore seems to weigh less than it does in air.
3. This loss in weight is exactly equal to the weight of the liquid displaced (Fig. 4:2).

Archimedes' Principle, therefore, may be stated as follows: An object, when immersed in a liquid, loses in apparent weight an amount equal to the weight of the liquid displaced.

or an alternative statement is:

The buoyant force of a fluid (liquid or gas) upon an object immersed in it, is equal to the weight of the fluid displaced.

Examples

1. A rectangular piece of metal, 15 cm. long, 6 cm. wide and 3 cm. thick, weighs 2700 gm. in air. Find its weight when immersed in water.

Weight of object in air	= 2700 gm.
Volume of object	= $15 \times 6 \times 3 = 270$ c.c.
Volume of water displaced	= 270 c.c.
Weight of water displaced	= 270 gm. (Density of water = 1 gm./cc.)
∴ Weight of object in water	= $2700 - 270$ (Archimedes' Principle)
	= 2430 gm.

2. Find the weight of the object in example 1, if it were immersed in carbon tetrachloride (S.G. = 1.60).

Weight of object in air = 2700 gm.

Volume of object = $15 \times 6 \times 3 = 270$ c.c.

Volume of carbon tetrachloride displaced = 270 c.c.

1 c.c. of carbon tetrachloride weighs 1.60 gm. (S.G. = 1.60)

$\therefore$ Weight of carbon tetrachloride displaced = $270 \times 1.60 = 432$ gm.

$\therefore$ Weight of object in carbon tetrachloride = $2700 - 432$

(Archimedes' Principle)

= 2268 gm.

Archimedes' Principle is used for the accurate determination of the specific gravity of solids and liquids (Chap. 6, Exp. 9, 10).

I : 12 PRINCIPLE OF FLOTATION

Archimedes' Principle applies to floating bodies as well as to those which are submerged in a fluid. When a body is floating in a liquid it appears to lose all its weight, as can be shown by lowering into water a block of wood, suspended by a thread from the hook of a spring balance (Fig. 4:3). As the wood settles more deeply into the water the reading of the spring balance decreases until, when the wood is floating, it records zero weight. The entire weight of the wood is now being supported by the upthrust of the water, this being equal to the weight of water displaced. We thus have, for floating bodies, the **Principle of Flotation**, which states that the weight

of a floating object is equal to the weight of the fluid (liquid or gas) it displaces when floating. A fairly heavy object will of course sink lower in the liquid in which it is floating than will a lighter object. In either case the submerged portion has displaced an amount of liquid equal to the weight of the floating object.

This statement is embraced in Archimedes' Principle, i.e., a body which floats has lost its whole weight. (Remember that this loss is an apparent one, not real. The pull of the earth on the floating body is still the same.) Experimental proof for this Principle is supplied in Chap. 6, Exp. 11.

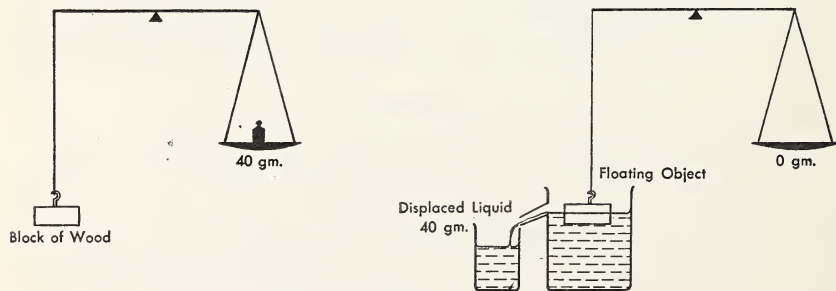


Fig. 4:3 Principle of Flotation.

Examples

1. An object loaded onto a flat barge 18 feet long and 10 feet wide, causes it to settle 2 inches deeper into the water. Calculate the weight of the object.

Volume of water displaced = $18 \times 10 \times 2/12 = 30$ cu. ft.

Weight of water displaced = $30 \times 62.5 = 1875$ lb.

(Density of water = 62.5 lb./cu. ft.)

$\therefore$ weight of object = 1875 lb. (Principle of Flotation)

2. A plastic tray 25 cm. long, 15 cm. wide is floating on water. A lead weight whose mass is 300 gm. when placed in it causes it to sink deeper into the water.

Calculate the depth to which it sinks.

Let the depth to which it sinks be x cm.

$\therefore$ Volume of water displaced = $25 \times 15 \times x = 375x$ c.c.

$\therefore$ Density of water = 1 gm./c.c.

$\therefore$ Weight of water displaced = $375x$ gm.

$\therefore$ Weight of water displaced = weight of floating object. (Principle of Flotation)

$\therefore$ Weight of water displaced = 300 gm.

$$375x = 300$$

$$x = \frac{300}{375} = .8$$

$\therefore$ Depth to which the tray sinks is .8 cm.

I : 13 HYDROMETERS AND THEIR USES

(a) Structure

The Principle of Flotation finds application in the hydrometer, which is a convenient instrument for the rapid determination of the specific gravity of liquids (Chap. 6, Exp. 12, 13). A common type of hydrometer consists of a cylindrical stem, graduated or containing a paper scale, an expansion of the stem called the float, and a bulb weighted with mercury or lead shot, the ballast, to make it float upright (Fig. 4:4). The float increases the buoyancy of the hydrometer.

The liquid whose specific gravity is to be determined is poured into a tall jar. The hydrometer is gently lowered into the liquid until it floats freely. The specific gravity of the liquid is indicated by the number on the scale which is even with the surface of the liquid. Since the hydrometer sinks until it has

displaced its own weight of the liquid, the lighter the liquid, the deeper the

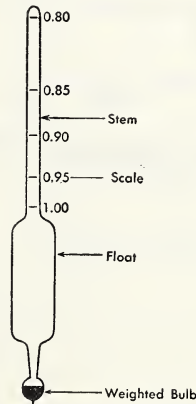


Fig. 4:4 Structure of a Hydrometer.

hydrometer will sink in it. Therefore, the largest specific gravity readings are

at the bottom of the scale, and the smallest at the top. Hydrometers used for liquids lighter than water have a large float, and scale gradations starting with a specific gravity of 1.000 at the bottom. Those used for liquids heavier than water have a small float, and scale gradations starting with 1.000 at the top. A universal hydrometer has 1.000 in the centre so that it may be used for

long and having a cross-sectional area of 1 sq. cm. It is weighted at one end with a plug of lead. On one face is marked

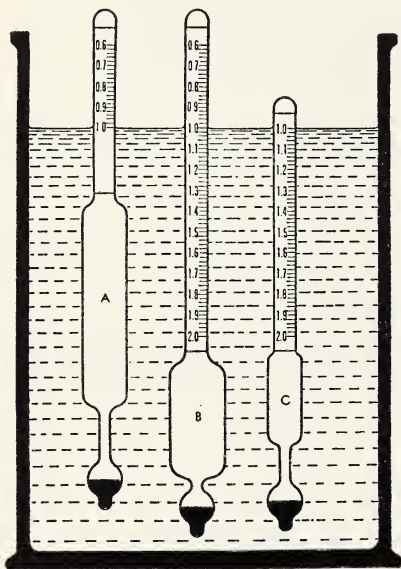


Fig. 4:5 Hydrometers of Different Types.
A—for liquids less dense than water
B—universal
C—for liquids denser than water

both kinds of liquids (Fig. 4:5). Since few scale readings can be accommodated above and below, such an instrument has a narrow range of usefulness.

(b) Principle

The principle of the hydrometer can best be illustrated by means of the simple hydrometer (Fig. 4:6). This consists of a straight wooden rod about 25 cm.

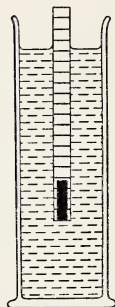


Fig. 4:6 Principle of the Hydrometer.

a centimetre scale, and the rod has been rendered impervious to water by dipping in hot paraffin.

Float the rod in water and note the depth to which it sinks, for example, 15 cm. Hence it displaces 15 c.c. or 15 gm. of water, and thus the weight of the hydrometer is 15 gm.

Now float it in some liquid whose specific gravity is to be determined, and note the level to which it sinks, for example, 20 cm. Hence the volume of the liquid displaced is 20 c.c. and the mass of an equal volume of water is 20 gm. But note, the weight of liquid displaced is equal to the weight of the hydrometer, namely, 15 gm. That is, the mass of liquid displaced is 15 gm. and the mass of an equal volume of water is 20 gm. It follows, therefore, that the specific gravity of the liquid is $15/20$ or .75, and its density is .75 gm. per c.c.

(c) Uses

Hydrometers, of course, are widely used beyond the walls of the physics laboratory for testing liquids. Industries using or preparing syrups, salt solutions, petroleum products, acids and heavy



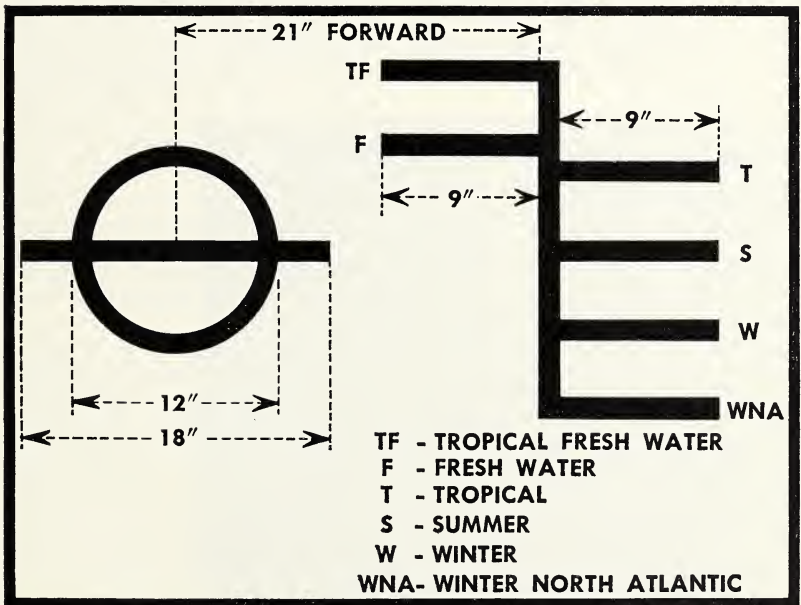
Courtesy of Exide Automotive Division

Fig. 4:7 Storage Battery Hydrometer.

chemicals make extensive use of them. The storage-battery hydrometer (Fig. 4:7) is used for testing the specific gravity of the acid in a battery, and hence for estimating the degree to which the battery is charged. Antifreeze hydrometers are used to measure the specific gravity of antifreeze and thereby indicate how low a temperature it can stand without freezing. Similarly lactometers are used in the testing of milk for checking possible dilution, and alcoholometers are used for estimating the strength of beers and wines.

I : 14 OTHER APPLICATIONS OF BUOYANCY

Archimedes' Principle and the Principle of Flotation apply wherever fluids are displaced, and the following ex-



Cunard Steamship Co. Ltd.

Fig. 4:8 The Plimsoll Mark.

The Plimsoll mark is painted amidships on the ship's hull to indicate safe-loading levels under different conditions (scale: $1\frac{1}{4}$ in. = 1 ft.).

amples are a few which show how important these principles are:

(a) Ships

Even when its hull is made of iron (density 7.9 gm. per c.c.) a ship floats on water because, being hollow, its average density is less than that of water. When it is launched it will sink to the level at which the weight of the water it displaces is equal to the entire weight of the ship, and hence the meaning of the term "displacement". A ship like the *Queen Elizabeth*, of 85,000 tons displacement, displaces 85,000 tons of sea-water when afloat. To ensure that it does not sink more deeply than is safe in the water, each ship has a safe-loading line, known as the Plimsoll line (Fig. 4:8) painted on its hull. Actually there are several such lines, to allow for regional and seasonal variations. These marks indicate the depth to which the ship may be safely loaded under the different conditions.

(b) Submarines

A submarine is a vessel with a cylindrically shaped enclosed hull fitted with ballast tanks at bow and stern and with smaller tanks on either side amidships. In order to submerge, the submarine allows water to enter these tanks until the total weight of the boat and ballast is nearly as great as that of the water it can displace. The submarine is now in "diving trim" and, by a proper use of horizontal or diving rudders, it can submerge completely and maintain its depth below the surface. In order to resurface, it forces the water out of its ballast tanks with compressed air. This action reduces its total weight until, when the weight is less than the upthrust, the ship rises.

(c) Floating Docks

When the hull of a great liner is to be serviced and reconditioned, a floating dock is used to lift it out of the water.

This dock consists, essentially, of a large flat tank divided into several compartments which can be filled with water to

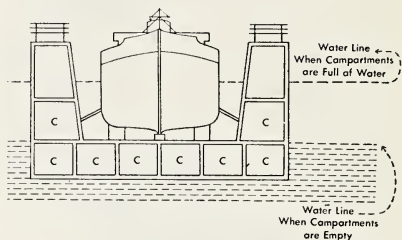


Fig. 4:9 Floating Dry-dock.

sink the dock to a sufficient depth for the ship to be drawn into it by tugs. The water is then blown out of the tanks by compressed air, and the dock rises, lifting the ship with it (Fig. 4:9).

(d) Balloons

When we apply Archimedes' Principle to air, we see that a body in air will experience a force of buoyancy equal to the weight of air it displaces. A balloon will rise if the weight of the air displaced is greater than the weight of the balloon envelope and its attachments. It will continue to rise until it reaches a level of more rarefied air where the weight of the air displaced is equal to that of the balloon.

The first balloons, built in 1783, employed hot air for upthrust, having open bottoms with burning braziers slung underneath them, but by August of the same year the French scientist Charles had sent up the first balloon to be filled with the newly discovered gas, hydrogen. Two years later a trip was made from France to England in such a balloon, motive power being provided by oars.

Modern balloons are made of a gas-tight silk fabric fitted with valves. Increased height is obtained by releasing water or sand ballast, while the descent

is brought about by slowly releasing the gas from the envelope. Then, since atmospheric pressure decreases with height, the gas inside the balloon expands as it rises (in accordance with Boyle's law) and thus there is danger that the balloon will burst at great heights. For this reason, in balloon ascents to high altitudes, the envelope is not filled to capacity at ground level.

The greatest height reached by a manned balloon, 72,395 feet (over 13½ miles) was made by Stevens and Anderson, two United States Army officers, at Rapid City, South Dakota, in 1935. Their trip was made in a tightly-sealed hollow metal sphere attached to a huge helium-filled balloon.

(e) Weather or Sounding Balloons

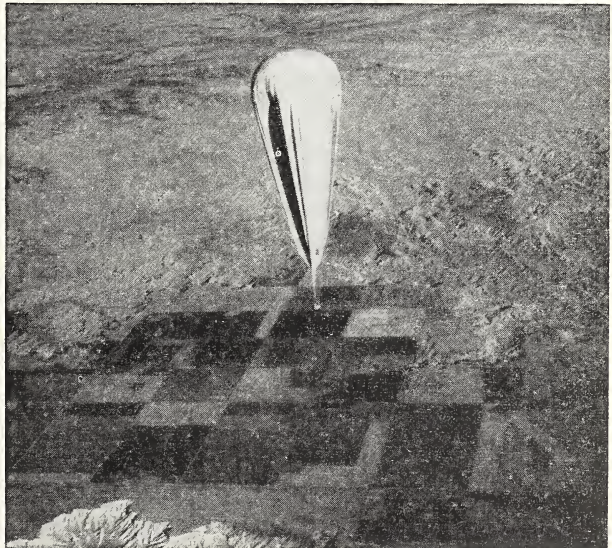
The main use of hydrogen balloons today is to collect information about the upper atmosphere for meteorological pur-

poses. These sounding balloons, as they are called, expand as they rise, until they spring a leak or burst, when the meteorological instruments which they carry are parachuted to earth. Temperature, pressure and humidity reports at various altitudes are automatically sent to weather stations by radio transmitters. Analysis of the readings have shown that sounding balloons have reached heights of 25 miles or more.

(f) Airships

An airship is a balloon built on a light rigid framework, propelled by air-screws and steered by rudders. The design of this type of craft developed rapidly in the early decades of this century. Although long flights were successfully made in these ships, a series of disasters resulting from the ease with which they caught fire, has caused their further development to be abandoned.

A Modern Sounding Balloon.



Wheeler Newspaper Syndicate

I : 15

QUESTIONS

A

1. (a) State Archimedes' Principle.
(b) In air a piece of iron whose volume is 100 c.c. has a mass of 890 gm. When this is immersed in water, calculate:
(i) the buoyant force of the water on it.
(ii) the weight of the iron in water.
2. Describe briefly how Archimedes' Principle is used to determine the specific gravity of (a) a solid denser than water (b) a liquid.
3. (a) State the Principle of Flotation.
(b) Show that it is a modification of Archimedes' Principle.
(c) When a piece of wood is floated in water in a graduated cylinder the level rises from 15.7 ml. to 18.3 ml.
(i) Calculate the mass of the wood.
(ii) If its specific gravity is 0.60, what is its volume?
4. Explain how Archimedes could have determined whether King Hiero's crown was pure gold or a mixture of gold and silver.
5. Explain how Archimedes' Principle or the Principle of Flotation applies to each of the following statements:
(a) In landing a fish, you find that it seems to weigh more when it is pulled out of the water than it does beneath the water surface.
(b) As a ship in harbour is being unloaded, it slowly rises higher in the water.
(c) In order to make a submarine submerge, large tanks aboard it are filled with water.
(d) The same ship with the same cargo will ride higher on the Atlantic Ocean than on the Great Lakes.
(e) Plimsoll lines are used on ships.
6. (a) What is the purpose of a hydrometer?
(b) Why are the smaller numbers of

the hydrometer scale near the top?
(c) Compare the size of float required for hydrometers used for denser and less dense liquids. Explain the difference.

7. State three methods used for finding the specific gravity of a liquid. Which of the three do you think is the most accurate? Why?

B

1. (a) If 15 c.c. of material weigh 45 gm. in air, find the weight when immersed in water.
(b) If 3 cu. ft. of a substance weigh 350 lb. in air, find the weight when immersed in water.
2. (a) Iron has a density of 7.8 gm. per c.c. Find the weight of 10 c.c. of it when immersed in water.
(b) A substance has a density of 187.5 lb. per cu. ft. Find the weight when 5 cu. ft. of it are immersed in water.
3. (a) If an object weighs 140 gm. in air and 115 gm. in water, what is the volume of the water displaced?
(b) If an object weighs 140 lb. in air and 115 lb. in water, what is the volume of the water displaced?
4. A piece of silver weighs 65.1 gm. in air and 58.9 gm. in water. Find its specific gravity.
5. A piece of metal weighs 500 gm. in air and 430 gm. in water. (i) What is its specific gravity? (ii) What is its volume?
6. A 15 lb. weight weighs only 9 lb. in water. (i) Find its specific gravity. (ii) Find its volume. (iii) Find its density.
7. A piece of metal weighing 120.4 gm. has a volume of 14.5 c.c. (i) What will it weigh in water? (ii) Find also the density of the metal.
8. An object weighs 42.2 gm. in air, 29.4 gm. in water and 25.6 gm. in a liquid.

Calculate the specific gravity of the liquid.

9. A metal weighs 56.3 gm. in air, 45.8 gm. when immersed in water and 48.6 gm. when immersed in a liquid. Calculate the specific gravity of (i) the metal (ii) the liquid.

10. A piece of metal weighs 138.8 gm. in air, 123.2 gm. in water and 125.7 gm. in a liquid. Find the specific gravity of the metal and of the liquid.

11. An object weighs 42.2 gm. in air and 29.4 gm. in water. How much will it weigh in a liquid of density 0.80 gm. per c.c.?

12. Was King Hiero's crown made of pure gold if in air it weighed 1500 gm., and when immersed in water it weighed 1400 gm.?

13. A rectangular block of soap 8 cm. long and 6 cm. wide floats in water with 2.5 cm. of its thickness submerged. Calculate the mass of the soap.

14. A cube of wood, side 50 cm., floats in water with its base horizontal and 6 cm. of its height above the surface. Find its density.

15. A wooden raft 5 ft. long and 4 ft. wide floats in water. When a person steps on the raft it sinks 1.5 inches deeper into the water. Calculate the person's weight.

16. A cork of volume 60 c.c. and density 0.24 gm. per c.c. floats in a liquid of density 0.85 gm. per c.c. Find the least weight required to sink it.

17. What volume of lead of density 11.2 gm. per c.c. will be required to sink

a piece of wood in water, the weight of the wood being 425 gm. and its volume 556 c.c.?

18. A block of wood of volume 100 c.c. floats in a liquid of specific gravity 1.2 with 75 c.c. immersed. Calculate the density of the wood.

19. A wooden hydrometer sinks in water to a depth of 18 cm. and in a liquid to a depth of 14 cm. What is the specific gravity of the liquid?

20. A hydrometer sinks in water to a depth of 15 cm. How far would it sink in a liquid whose specific gravity is 0.80?

21. A hydrometer sinks to a depth of 12 cm. in a liquid whose specific gravity is 1.7. To what depth would it sink in water?

22. A piece of wood whose volume is 150 c.c. floats with $\frac{2}{3}$ of its volume submerged in water. Find its mass.

23. A piece of wood whose mass is 75.0 gm. floats in water with $\frac{3}{5}$ of its volume above the surface. Find its volume.

24. A piece of cork of density 0.25 gm. per c.c. floats in a liquid of density 1.2 gm. per c.c. What proportion of the volume of the cork will be immersed?

25. An object floats in water with half its volume submerged. How much will be submerged when it floats in a liquid of specific gravity 1.5?

26. To what depth will a block of wood 20 cm. high and of density 0.63 gm. per c.c. sink in a liquid of density 0.90 gm. per c.c.?

CHAPTER 5

FORCE, WORK AND POWER

I: 16 MEANING OF FORCE

Our first ideas of the nature of force are derived from muscular sensations. A child soon becomes acquainted with various pushes and pulls which act upon him or upon other objects. A boy pulling a sled is using a force (Fig. 5:1). A base-



Fig. 5:1 To Illustrate Force.

ball player throwing a ball uses a force. Thus we may say that a force is that which produces motion. However, this is only a partial definition.

Suppose that a small boy is trying to move a refrigerator, but is unable to move it. We must agree that he is using

a force although no motion is produced. We must qualify our above definition of a force to include "that which tends to produce motion".

Suppose that you are playing football, and one of the opposing side is rushing forward with the ball. You tackle him and stop him, or as it often happens you don't stop him but slow him down. There is no doubt that you used force, so we must further qualify our definition of force to include "that which stops motion or tends to stop it".

We must consider one more case. Suppose a baseball player swings his bat at a ball and in so doing hits it into fair territory or fouls it. In applying a force the batter caused the ball to move faster or change its direction. In order to cover these cases we must add to our definition of force to include "that which causes or tends to cause a change in rate or direction of motion".

We may now define **force** as that which changes, or tends to change, the state of rest or motion of a body.

The earth is constantly exerting a force on all bodies around us, causing them to move or tend to move towards it. This pull is known as the **force of gravity**. Everyone knows that when he weighs himself he is measuring the downward force he exerts on the foot-board of the scales. This downward force is the force of gravity and we call it our weight (Sec. I:2). Weight may

be measured by the use of a spring balance (Fig. 5:2) or a coiled spring (Chap. 6, Exp. 14).



Fisher Scientific Co.

Fig. 5:2 Spring Balance.

I: 17 MEASUREMENT OF FORCE

The pull of the earth on a body whose mass (Sec. I:2) is one pound is called a **pound-weight** or pound-force (abbreviated lb. wt.). In the metric system the **gram-weight** or gram-force (gm. wt.) is defined as the pull of the earth on a body whose mass is one gram.

The weight of a body, or the pull of the earth on it, is not the same at all parts of the earth's surface. Hence to define the pound-weight and the gram-weight exactly it would be necessary to specify the point where the weighing is done. However, the variations of weight with position on the earth are so small as to be negligible for our purposes.

Sir Isaac Newton (1642-1727) found out that the earth not only attracts bodies on or close to its surface, but it also attracts the celestial bodies. He therefore assumed that every body in the universe attracts every other body; that is, the force of gravity is universal. The amount of this force depends upon the masses of the attracting bodies and upon the distance between them. The greater the masses of the bodies, the greater is the attraction; the greater the distance between them the smaller is the attraction. In fact, the attraction between two bodies varies directly as the product of their masses and inversely as the square of the distance between their centres; that is,

$$\text{Force varies as } \frac{m_1 m_2}{d^2}$$

This is known as **Newton's Law of Universal Gravitation**.

Example

- (a) Compare the force of the earth's attraction on a mass of one pound on the earth's surface with the force of the moon's attraction on the same mass on the moon's surface, being given that the mass of the earth is approximately one hundred times that of the moon, and the radius of the earth is approximately four times that of the moon.
- (b) What is the weight of this mass on the moon's surface?

(a) Force exerted by moon = F_m	Force exerted by earth = F_e
Mass of moon = M	Mass of earth = $100M$
Radius of moon = R	Radius of earth = $4R$

$$F_m \propto \frac{M \times 1}{R^2}$$

$$F_e \propto \frac{100 M \times 1}{(4R)^2}$$

$$\frac{F_e}{F_m} = \frac{\frac{100 M \times 1}{16 R^2}}{\frac{M \times 1}{R^2}} = \frac{100}{16} = \frac{25}{4}$$

(b) $\therefore F_e = 1 \text{ lb. wt.}$

$$\frac{1}{F_m} = \frac{25}{4}$$

$$\therefore F_m = \frac{4}{25} = \frac{1}{6} \text{ approximately}$$

$\therefore$ The weight of this mass on the moon's surface is approximately $\frac{1}{6} \text{ lb. wt.}$

I: 18 MEANING OF WORK

A boy exerts a force of 50 lb. wt. on a wall but does not move it. Although an effort was exerted no effect was produced and, therefore, we say that no work was accomplished. In order that work be done, in a scientific sense, a

force must move an object through some distance. The amount of work depends on the size of the force and the distance through which the force acts. If you lift a mass of 1 pound through a distance of 1 foot, you have done a certain amount of work. If you lift a 1-pound mass through a distance of 2 feet, you have done twice as much work (Fig. 5:3).

In its simplest mechanical form **work** is defined as the force times the distance through which the force acts.

$$\text{Work} = \text{force} \times \text{distance} \\ \text{or } W = Fs$$

I: 19 MEASUREMENT OF WORK

Since work is defined as the product of force and distance the units of work are expressed by a combination of the units of each. If the force is measured in pounds-weight and the distance in feet, we call our unit of work the foot-pound weight (ft. lb. wt.). One **foot-pound weight** of work is done when a force of 1 pound-weight acts through a distance of 1 foot.

In the metric system a unit of work is the **gram-weight centimetre** (gm. wt. cm.) which is the amount of work done when a force of 1 gram-weight acts through a distance of 1 centimetre.

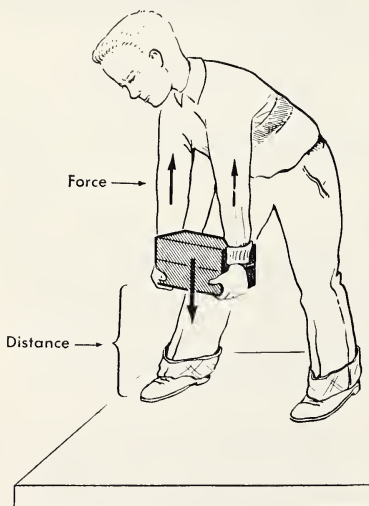


Fig. 5:3 To Illustrate the Meaning of Work.

Example

How much work is done when a 50 lb. body is lifted 3 feet?

In this case work is done by overcoming the force of gravity.

$$\begin{aligned} F &= 50 \text{ lb. wt.} & W &= Fs \\ S &= 3 \text{ ft.} & W &= 50 \times 3 \\ & & W &= 150 \end{aligned}$$

∴ The work done is 150 ft. lb. wt.

We know that it is much easier to move a body along the surface of a floor than it is to lift it. This is because, in this case, we are overcoming the force of friction instead of the force of gravity.

Example

A mass of 50 pounds rests on a level floor. A force of 10 pounds-weight is required to slide it across the floor. How much work is done in moving it through a distance of 3 feet?

$$\begin{aligned} F &= 10 \text{ lb. wt.} & W &= Fs \\ S &= 3 \text{ ft.} & W &= 10 \times 3 \\ & & W &= 30 \end{aligned}$$

∴ The work done is 30 ft. lb. wt.

I: 20 MEANING OF POWER

A man does the same amount of work when he climbs a flight of stairs in one minute as he does if he climbs the same flight of stairs in half an hour but he does not use the same amount of power. **Power** is defined as the rate at which work is done. While force involves one factor only, and work involves two factors, force and distance, power is concerned with three factors, force, distance and time.

$$\text{Power} = \frac{\text{Work}}{\text{Time}}$$

or

$$P = \frac{Fs}{t}$$

In climbing the stairs in one minute the man developed thirty times as much power as he does in climbing the same stairs in half an hour. The more work that is done in a given time, the greater is the power. The less time it takes to do a certain amount of work, the greater is the power.

I: 21 UNITS OF POWER

In the English system an obvious unit of power is 1 foot-pound weight per second. With the invention of the steam engine, a larger unit became necessary. The horsepower was defined by James Watt, the famous Scottish inventor. His engines replaced the horses used in working mine pumps. Watt experimented with a number of strong dray horses and finally decided that a good value for a horsepower was 33,000 foot-pounds weight per minute. One **horsepower** is therefore defined as 33,000 foot-pounds weight per minute or 550 foot-pounds weight per second.

$$\begin{aligned} \text{Horsepower} &= \frac{\text{Foot-pounds weight}}{\text{Minutes} \times 33000} \\ &= \frac{\text{Foot-pounds weight}}{\text{Seconds} \times 550} \end{aligned}$$

In the metric system the gram-weight centimetre per second or kilogram-weight metre per second is used. The most common metric unit of power is the watt or the kilowatt, which equals one thousand watts. One horsepower is equal to 746 watts or approximately $\frac{3}{4}$ kilowatt.

$$1 \text{ horsepower} = 746 \text{ watts}$$

Examples

1. If a boy weighing 110 pounds-weight runs up a staircase 9 feet high in 3 seconds, what horsepower is he developing?

$$\begin{aligned} F &= 110 \text{ lb.-wt.} \\ s &= 9 \text{ ft.} \\ t &= 3 \text{ sec.} \end{aligned}$$

$$P = \frac{Fs}{t} \quad \therefore P = \frac{110 \times 9}{3} = 330 \text{ ft. lb. wt. per sec.}$$

$$= \frac{330}{550} = 0.6$$

$$\therefore \text{Power developed} = 0.6 \text{ H.P.}$$

2. A train weighing 100 tons-weight travels on the level at a uniform speed of 45 miles per hour. The frictional resistances are equal to 10 pounds-weight per ton. Find the horsepower at which the engine is working.

Total frictional resistances that must be overcome $= 10 \times 100 = 1000 \text{ lb. wt.}$

$$\begin{aligned} \therefore \text{Force exerted, } F &= 1000 \text{ lb. wt.} \\ \text{Speed} &= 45 \text{ m.p.h.} = 66 \text{ ft. per sec.} \\ \therefore s &= 66 \text{ ft.} \\ t &= 1 \text{ sec.} \end{aligned}$$

$$P = \frac{Fs}{t}$$

$$P = \frac{1000 \times 66}{1} = 66000 \text{ ft. lb. per sec.}$$

$$= \frac{66000}{550} = 120$$

$$\therefore \text{Power at which engine is working} = 120 \text{ H.P.}$$

In any machine it is apparent that not all the power developed can be used to produce useful work. Some power is required to overcome resistances due to friction in the moving parts. The efficiency of the machine is the comparison of the useful work that the machine produces with the work that we must provide to make it operate (Chap. 6, Exp. 15).

$$\text{Efficiency} = \frac{\text{Useful work}}{\text{Total work}} \text{ or } \frac{\text{Output}}{\text{Input}}$$

Example

A man weighing 165 pounds-weight is raised 10 feet in 3 seconds while standing in an elevator which is operated by a 5 H.P. engine. Find the efficiency of the engine.

$$\begin{aligned} \therefore P &= 5 \text{ H.P.} = 5 \times 550 \text{ ft. lb. wt. per sec.} \\ t &= 3 \text{ sec.} \\ \therefore \text{Work input} &= 5 \times 550 \times 3 = 8250 \text{ ft. lb. wt.} \\ \therefore F &= 165 \text{ lb. wt.} \\ s &= 10 \text{ ft.} \\ \therefore \text{Work output} &= 165 \times 10 = 1650 \text{ ft. lb. wt.} \\ \therefore \text{Efficiency} &= \frac{\text{Output}}{\text{Input}} = \frac{1650}{8250} = \frac{1}{5} \text{ or } 20\% \end{aligned}$$

Question: How has the remaining 80% of the input been utilized?

Alternative Solution

Power input to engine = 5 H.P.

$$\text{Power output of engine} = \frac{\text{ft. lb. wt.}}{\text{sec.} \times 550} = \frac{165 \times 10}{3 \times 550} = 1 \text{ H.P.}$$

$$\therefore \text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{1}{5} \text{ or } 20\%$$

I : 22

QUESTIONS

A

FORCE:

1. Define: (a) mass; (b) weight; (c) force.

2. Define: (a) pound-weight; (b) gram-weight, and state how you abbreviate each.

3. If a hole were bored through the earth and a ball dropped into it, where would it come to rest? Explain.

4. If one were to take a spring balance (Fig. 5:2) and a beam balance (Fig. 6:3) to the moon to weigh a certain mass, would the two balances show the same readings? Explain.

5. (a) State Newton's Law of Universal Gravitation.

(b) State Hooke's Law.

6. Would a gram mass weigh more on the sun than on the earth? Explain.

7. What is the force of gravity on a one-pound mass?

8. How much would you weigh on the surface of the moon?

9. If given a long spiral spring, a pound mass, and a bag of sugar, how would you determine the weight of the sugar?

WORK:

10. Explain what is meant by work in the scientific sense.

11. What two factors must be known so that the work that is done may be computed?

12. Name a unit for measuring work in both the English and metric systems. Define each.

13. Name two forces which must usually be overcome in doing work.

14. What is friction?

15. Is friction always a hindrance to work? Explain.

16. Why is it easier to push a 50-lb. body along a smooth surface than to lift it?

POWER:

17. What is the scientific meaning of power?

18. How does power differ from force and work?

19. What is the definition of horsepower?

20. Does a horse always work at the rate of 1 horsepower? Explain.

21. What is the definition of efficiency?

22. Can the efficiency of any machine ever be greater than 100%? Explain.

23. Compare the work you would do in going up a flight of stairs 12 feet high with the work done in climbing a vertical ladder of the same height.

24. Should the pay a labourer receives be based upon his power or his total work? Explain.

B

FORCE:

1. A boy can jump 4 feet high on the surface of the earth. How high would he be able to jump on the surface of the moon?

2. A boy can throw a ball 50 feet up into the air on the earth's surface. How high would he be able to throw it on the surface of the moon?

3. A man weighs 160 lb. wt. on the surface of the earth. How much would he weigh 4,000 miles above the surface? (Assume that the diameter of the earth is 8,000 miles.)

4. A man weighs 160 lb. wt. on the earth's surface. How high into space would he have to travel in order that he weigh only 10 lb. wt.?

5. A body weighs 1,000 gm. wt. on the surface of the earth. If it were moved to a planet twice the mass of the earth, and the radius twice that of the earth, how much would it weigh a distance of one radius of the planet away from the planet?

WORK :

6. How much work is done when

(a) a 7 lb. wt. body is lifted onto a table 3 ft. high,

(b) a man weighing 165 lb. wt. climbs a ladder 15 ft. high,

(c) a chair weighing 20 lb. wt. is dragged 12 ft. across a floor if the average frictional resistance is 3 lb. wt.?

7. A man weighing 180 lb. wt. carries a parcel weighing 50 lb. wt. to the top of a house 30 ft. high.

Find (a) the total work done.

(b) the useful work.

8. If a pressure of 25 lb. wt. per sq. in. acts on the circular piston (radius 10 in.) of a steam engine, and drives the piston through a distance of 4 ft., find the work done.

9. A block of wood 4 ft. 6 in. long is 1 ft. thick. It weighs 400 lb. wt. If the block lies on its side, how much work does a man do in standing the block on end?

POWER :

10. (a) How much work does a man

weighing 180 lb. wt. do in climbing a flight of stairs 20 ft. high?

(b) What horsepower does he develop if he climbs the stairs in 10 seconds?

11. (a) If a horse pulls with a force of 240 lb. wt. to keep a 900-lb. wagon moving, how much work does he do in pulling the wagon $\frac{1}{4}$ mile?

(b) If he moves at the rate of 3 mi. per hour, what H.P. does he develop?

12. A man pushes a 100-lb. cake of ice up an inclined plane to a platform $5\frac{1}{2}$ ft. high in 10 sec. Neglecting friction, what is his rate of working?

13. A girl exerts a force of 3 lb. wt. through a distance of 1 ft. every time she turns the handle of an egg beater through one revolution. If she makes 220 r.p.m., at what horsepower is she working?

14. A force of 200 lb. wt. is necessary to push an automobile along a road at a speed of 30 m.p.h. How many horsepower must the engine deliver to accomplish this?

15. A horse exerts a force of 55 lb. wt. while moving at the rate of 6.0 m.p.h. At what rate is the horse working?

16. A motor-driven saw exerts a force of 2.5 lb. wt. while moving at the rate of 110 ft. per sec. How much horsepower must be supplied to the saw?

17. A 1 horsepower motor drives a saw so that the cutting blade moves at a rate of 110 ft. per sec. What force does the blade exert?

18. An elevator is made to rise by a 10 horsepower motor. The weight of the elevator and its load is 1,100 lb. wt. How long will it take the motor to raise the elevator a distance of 100 ft.?

19. How far can a horse working at the rate of 1 horsepower draw a load requiring a pull of 100 lb. wt. in one minute?

20. How long will it take an automobile

engine with an output of 20 horsepower and exerting a force of 220 lb. wt. to move a car through a distance of 100 ft.?

21. How many tons of coal per hour can be lifted from a mine by an elevator 50% efficient and driven by a 10 horsepower motor? The depth of the mine is 100 ft.

22. At what speed in miles per hour will an engine with an output of 26.4 horsepower and a force of 165 lb. wt. move a car?

23. How high can a pump of 2 horsepower rating raise 110 gallons of water in 1 minute? (1 gal. of water weighs 10 lb. wt.)

24. A turbine with an output of 10,000 horsepower and an efficiency of 80% operates at the foot of a waterfall 110 ft. high. How many cubic feet of water per second does the turbine use? (Density of water is 62.5 lb. per cu. ft.)

25. A boy weighing 120 lb. wt. runs up 30 steps, each rising 6 in., in 12 sec. What is his rate of working in horsepower?

26. What horsepower is required to pump 1,000 gal. of water out of a well 60 ft. deep in 10 minutes? Consider the weight of 1 gal. of water to be 10 lb. wt.

27. If 20,000 cu. ft. of water per second flow over a waterfall 165 ft. high, what would be the available horsepower if none were wasted?

28. What must be the output horsepower of a fire engine that will throw 100 cu. ft. of water per minute to a height of 150 ft.?

Consider air resistance too slight to affect the result.

29. What is the input horsepower of the engine used in problem 4 if the efficiency is 70%?

30. How many cubic feet of water can a 125 horsepower pump raise to a height of 50 ft. in 1 minute? Efficiency of pump is 60%.

31. How many tons of gravel per hour can be hoisted to a height of 10 ft. by an elevator having an efficiency of 50% when driven by a 20 horsepower engine?

32. How much horsepower is required to drive a 2,400-lb. car up a hill rising 10 ft. in every 100 ft. of road at 30 m.p.h., if all the forces of friction add up to 210 lb. wt.?

33. The mean flow of the Niagara River is 220,000 cu. ft. per second, with a fall of 160 ft. Calculate the available horsepower.

34. If a pressure of 25 lb. wt. per sq. in. acts on a circular piston (radius 10 in.) of a steam engine, and drives the piston through a distance of 5 ft., find the work done.

35. A train and its engine, weighing 200 tons wt., are kept moving on a level track at 30 m.p.h. If the resistance to motion is 25 lb. wt. per ton, what horsepower is developed by the engine?

36. The total resistance of a car travelling on a level road is 550 lb. wt. Find the maximum distance it will travel in 10 seconds if it is powered by a 100 horsepower engine. Efficiency of engine is 80%.

CHAPTER 6

EXPERIMENTS ON MECHANICS

INTRODUCTION

Before proceeding with the following experiments the student should review the following techniques used in measurement.

A. — Use of the ruler

1. Avoid using the ends of the ruler.
2. Place your eye directly above the point where the reading is to be taken to avoid the error due to parallax.

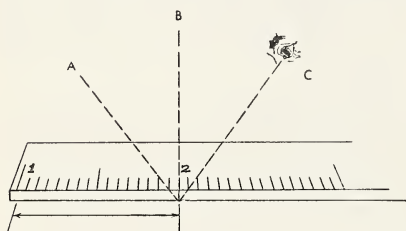


Fig. 6:1 Measuring Length with a Ruler—How to Avoid the Error Due to Parallax.

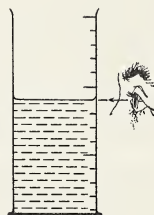


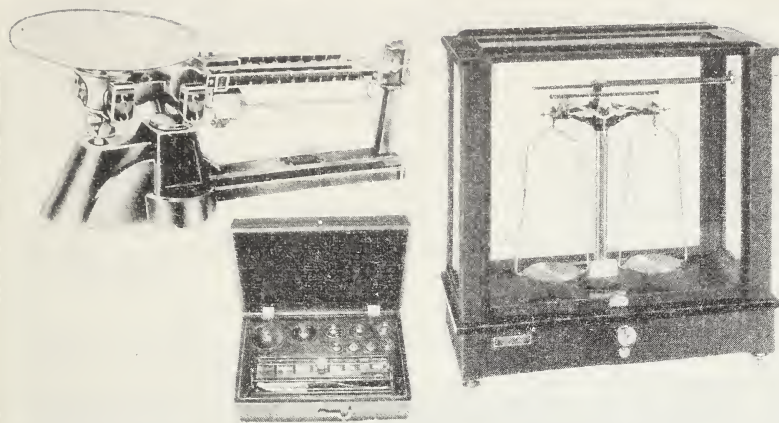
Fig. 6:2 Measuring Volume with a Graduated Cylinder.

B. — Use of the graduated cylinder

Place your eye directly opposite the centre of the meniscus curve. Take the reading at this level.

C. — Use of the balance

1. Clean and level the balance.
2. Support the beam of the balance on the knife-edge as demonstrated by the instructor.
3. Adjust for zero reading with all weights removed. Note that in all readings the pointer should swing an equal number of divisions on either side of the zero mark on the scale. Do not wait for the pointer to come to rest.
4. Place object to be weighed on the centre of the left pan of the balance.
5. Commencing with a weight that is definitely too heavy on the right-



A

B

Fisher Scientific Co.
Canadian Laboratory Supplies Ltd.

Fig. 6:3 The Balances A—Triple-beam balance.

B—Equal-arm balance and box of weights.

hand-pan of the equal-arm balance (or on the arm of the triple-beam balance), systematically reduce the weight until balance is attained.

6. Total the weights used.

7. Disengage the knife-edge and return all weights to their box or to their zero position.

EXPERIMENT 1

To determine the density of a regular solid. (REF. SEC. I:5)

Apparatus

Rectangular solid, ruler (graduated in mm.), balance.

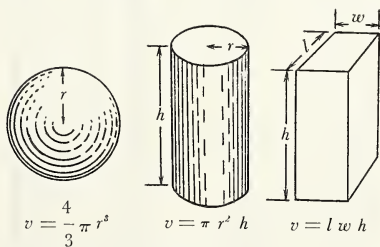


Fig. 6:4

Method

1. Carefully measure to the nearest millimetre the length, width and

thickness of a rectangular solid.* Record your measurements, and calculate the volume of the object in cubic centimetres.

2. Determine the mass of the object and record it in grams.

Observations	Length	=	cm.
	Width	=	cm.
	Thickness	=	cm.
	Mass	=	gm.

Calculations

1. What is the volume of the object?
2. Determine the mass of one cubic centimetre.
3. What is the average of the results obtained by the class?

Conclusion

What is the density of this material?

Questions

1. What is the correct value for the density of this material? (Table p. 21).
2. Express the difference between the class average and the true value as a percentage of the true value. This is a measure of the experimental error.
3. Suggest sources of experimental error.

* *Note* The density of other regular solids, such as a cylinder (Volume = $\pi r^2 h$), or a sphere (Volume = $\frac{4}{3} \pi r^3$) may be determined in a similar way (Fig. 6:4).

EXPERIMENT 2

To determine the density of an irregular solid (rubber stopper).
(REF. SEC. I:5)

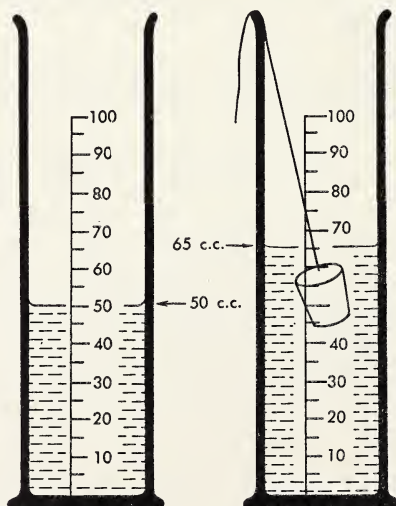


Fig. 6:5

Apparatus

Rubber stopper, thread, graduated cylinder, water, balance.

Method

1. Determine the mass of the object and record it in grams.
2. Half fill a graduated cylinder with water. Note and record the volume of the water. Tie a thread to the object and carefully lower it into the water until it is completely immersed. Note and record the final volume of the water and object. Determine the volume of the object and record it in cubic centimetres.

Observations

Mass of object	=	gm.
Initial volume of water	=	c.c.
Final volume of water and object	=	c.c.
∴ Volume of object	=	c.c.

Conclusion

What is the density of this material?

Question

Why should the object be weighed before its volume is determined?

EXPERIMENT 3

To determine the density of a liquid by measurement. (REF. SEC. I:5)

Apparatus

Beaker, graduated cylinder, balance, liquid (water, alcohol, etc.).

Method

1. Determine the mass of a clean dry beaker.
2. Add about 50 c.c. of the liquid to the beaker, weigh, and hence determine the mass of the liquid used.
3. Pour the liquid into a graduated cylinder and determine its volume.

Observations

Mass of beaker	=	gm.
Mass of beaker plus liquid	=	gm.
∴ Mass of liquid	=	gm.
Volume of liquid	=	c.c.

Calculations

Determine the mass of one cubic centimetre.

What is the average of the results obtained by the class?

Conclusion

What is the density of this liquid?

Questions

1. What is the correct value for the density of this liquid? (Table p. 21)
2. Calculate the percentage error.
3. Suggest sources of experimental error.
4. If the balance at your disposal is suitable, a graduated cylinder, instead of a beaker, could be used in steps 1 and 2 in the above experiment. Why should this tend to reduce the experimental error?

EXPERIMENT 4

To determine the specific gravity of a liquid by means of the specific gravity bottle. (REF. SEC. I:7)

Apparatus

Specific-gravity bottle, water, balance, liquid (carbon tetrachloride, alcohol, etc.)

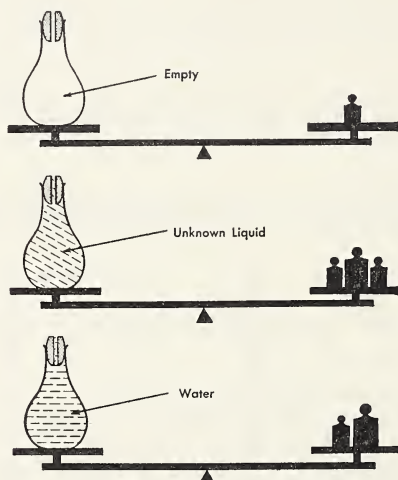


Fig. 6.6

Method

1. Carefully clean and dry the bottle. Determine its mass.
2. Fill completely with the liquid whose specific gravity is to be determined. Insert the stopper, wipe off any excess liquid that exudes through the opening. Determine the mass of the bottle plus the liquid.
3. Pour out the liquid. Rinse out the bottle with water. Fill the bottle completely with water. Determine the mass of the bottle plus the water.

Observations

Mass of specific-gravity bottle empty	=	gm.
Mass of specific-gravity bottle full of liquid	=	gm.
∴ Mass of liquid	=	gm.
Mass of specific-gravity bottle full of water	=	gm.
∴ Mass of water	=	gm.

Conclusion

What is the specific gravity of the liquid?

Questions

1. Define specific gravity.
2. Calculate the percentage error.
3. Suggest sources of experimental error.
4. What is the purpose of the hole through the centre of the stopper of the specific-gravity bottle?

EXPERIMENT 5

To determine the specific gravity of a liquid by using a U-tube.

Apparatus

Glass U-tube, mercury, water, liquid (alcohol, carbon tetrachloride, etc.).

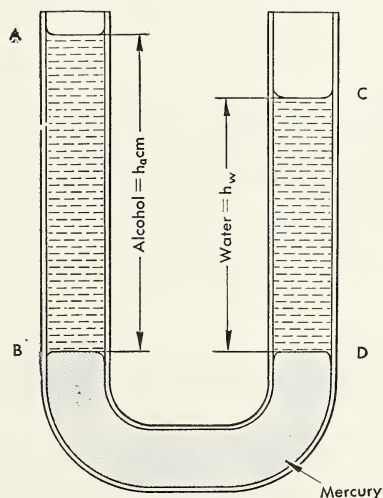


Fig. 6:7

Method

1. Put some mercury into the U-tube. Note the levels in each arm of the tube.
2. Pour some alcohol into one arm of the U-tube.
3. Pour water into the other arm of the U-tube until the level of the mercury is restored.
4. Measure the height of alcohol and the height of water above the mercury.
5. Repeat this experiment using other liquids provided.

Observations

1. Height of alcohol =
2. Height of water =

Calculations

1. Calculate the specific gravity of alcohol by using the formula,

$$\text{Sp. Gr.} = \frac{h_w}{h_a}$$

2. On what principle does this method depend?

Questions

1. Describe the changes in the mercury levels at B and D as you proceeded with the experiment.
2. What precautions must you take in measuring liquid heights? What is a meniscus?
3. What can you say about the weights of alcohol and water when the levels of mercury at B and D are the same?
4. Why is the column of alcohol higher than the level of water?
5. If the level of alcohol is h_a , and the level of water is h_w , show that the specific gravity of alcohol is $\frac{h_w}{h_a}$

EXPERIMENT 6

To determine the specific gravity of a liquid by using Hare's apparatus.

Apparatus

Hare's apparatus, two beakers, water, liquid (alcohol, carbon tetrachloride, etc.).

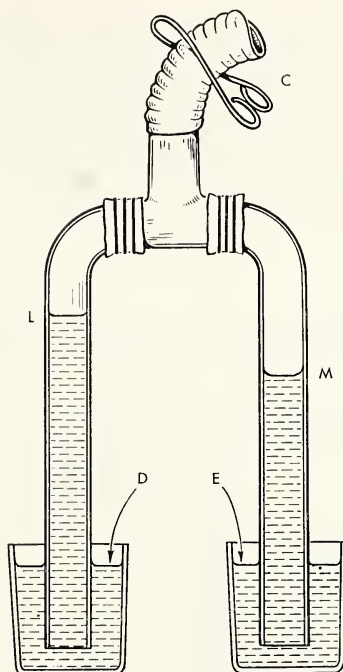


Fig. 6:8

Method

1. Put some alcohol in one beaker and some water into the other.
2. Place one arm of the inverted U-tube into the beaker of alcohol and the other into the beaker of water.
3. Suck the air out of the apparatus until the liquids rise in the arms.
4. Shut off supply of air by pinchcock at C.
5. Measure the columns of alcohol and water.
6. Repeat experiment using other liquids provided.

Observations

1. Height of alcohol =
2. Height of water =

Calculations

Calculate the specific gravity of alcohol.

Questions

1. Why did the liquids rise when you sucked some air out?

2. Make sure that you measure the heights of liquids from the surface of the liquid in the beaker to the meniscus. Why?
3. The weight of the column DL of alcohol is equal to the weight of the column EM of water. Why do we know this?
4. Using the fact that the weight of alcohol is equal to the weight of water, prove that the specific gravity of alcohol is equal to height of column of water over the height of column of alcohol.

$$\left(\text{Sp. Gr.} = \frac{h_w}{h_a} \right)$$

EXPERIMENT 7

To demonstrate Archimedes' Principle. (REF. SEC. I:11)

Apparatus

Balance, bucket and cylinder apparatus, beaker, water.

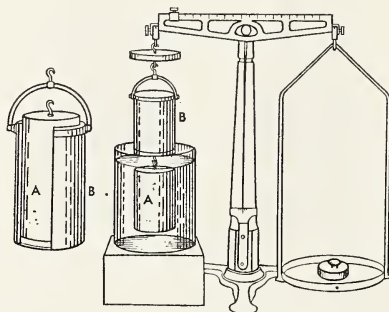


Fig. 6:9

Method

1. Hook the cylinder A on the bottom of the bucket B. Suspend them from the hook on the balance. Adjust the weights until the balance is in equilibrium.
2. Completely immerse the cylinder in a beaker of water. Be sure that the cylinder does not touch the bottom or sides of the beaker. Note the effect on the equilibrium.
3. Carefully add water to the bucket until it is completely full. Again note the effect on the equilibrium.

Observations

1. What was observed when the cylinder was completely immersed in the water?
2. What was observed when the bucket was filled with water?

Conclusions

1. Why was the equilibrium disturbed in step 2?
2. Why was the equilibrium restored in step 3?
3. State Archimedes' Principle.

Questions

1. Why do objects apparently weigh less when immersed in a liquid?
2. What would be the effect of immersing the object in a denser liquid?

EXPERIMENT 8

Alternative method to demonstrate Archimedes' Principle.

(REF. SEC. I:11)

Apparatus

Balance, object (glass stopper), beaker, overflow can, catch bucket, water, several other liquids (alcohol, carbon tetrachloride, brine, etc.).

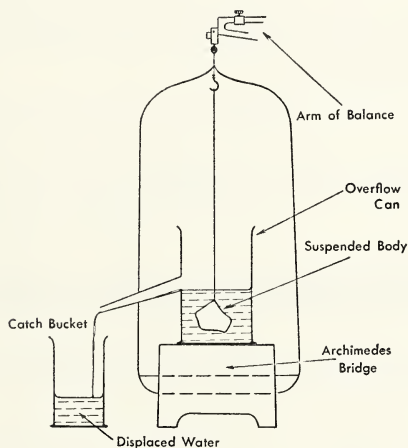


Fig. 6:10

Method

1. Suspend the object from the hook on the balance. Determine its mass in air.
2. Completely immerse the object in a beaker of water. Be sure that it does not touch the beaker. Weigh the object while immersed in water.
3. Weigh a dry empty catch bucket.

4. Completely fill an overflow can with water. Let any excess water flow freely from the spout and discard it. Do not disturb the overflow can. Place the catch bucket under the spout. Carefully lower the object into the water and catch all of the overflow in the bucket. Weigh the catch bucket and overflow water.
5. Repeat the above using other liquids and fill in the table below.

Observations

LIQUID USED	WATER	ALCOHOL	CARBON TETRACHLORIDE
Weight of object in air			
Weight of object in liquid			
$\therefore$ Apparent loss of weight in liquid			
Weight of empty catch bucket			
Weight of bucket plus displaced liquid			
$\therefore$ Weight of displaced liquid			

Conclusions

1. How does the apparent loss of weight compare with the weight of liquid displaced?
2. State Archimedes' Principle.

Questions

1. Why is a glass stopper an ideal solid to use in the above experiment?
2. What type of solid must be avoided?

EXPERIMENT 9

To determine the specific gravity of a solid which is more dense than water using Archimedes' Principle. (REF. SEC. I:11)

Apparatus

Balance, beaker, water, thread, several solid objects more dense than water.

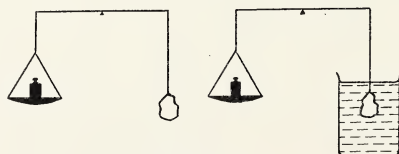


Fig. 6:11

Method

1. Suspend a solid object by a thread from the hook on the balance. Determine its weight in air.

EXPERIMENTS ON MECHANICS

2. Completely immerse the object in a beaker of water. Be sure that it does not touch the beaker. Determine the weight of the object when immersed in water.
3. Repeat the above weighings for other objects supplied and fill in the table below.

Observations

OBJECT	WEIGHT IN AIR	WEIGHT IN WATER	APPARENT LOSS IN WEIGHT
1.			
2.			
3.			

Calculations

Weight of object in air = gm.

Apparent loss in weight = gm.

∴ Weight of water displaced = gm. (Archimedes' Principle)

∴ Specific gravity = $\frac{\text{Weight of object in air}}{\text{Weight of equal volume of water}}$

∴ Specific gravity =

Conclusion

What is the specific gravity of the object?

Questions

1. Calculate the percentage error.
2. Suggest sources of experimental error.
3. Explain how the weight of an equal volume of water was determined.
4. State the density of the above objects in the metric system of units.
5. Discuss advantages and disadvantages of this method for finding density compared with the method used formerly (Exp. 2).

EXPERIMENT 10

To determine the specific gravity of a liquid using Archimedes' Principle. (REF. SEC. I:11)

Apparatus

Balance, glass stopper, thread, several beakers, water, liquid (alcohol, carbon tetrachloride, etc.).

Method

1. Suspend the object by a thread from the hook on the balance. Determine its weight in air.

- 2. Immerse the object in a beaker of water, being careful not to let it touch the beaker. Determine the weight of the object when immersed in water.
- 3. Rinse the object in a reserve supply of the liquid whose specific gravity is to be determined. Immerse the object in a beaker of this liquid and again weigh.
- 4. Repeat for other liquids supplied.

Observations

LIQUID USED	WEIGHT OF OBJECT IN AIR	WEIGHT OF OBJECT IN WATER	WEIGHT OF OBJECT IN LIQUID
Alcohol			
Carbon tetrachloride			

Calculations

Mass of water displaced = gm.
Mass of liquid displaced = gm.
Calculate the specific gravity of this liquid.

Conclusion

What is the specific gravity of the liquid used?

Questions

- 1. Calculate the percentage error.
- 2. Suggest sources of error.
- 3. Explain how the mass of water displaced or of liquid displaced was obtained in the above experiment.
- 4. Why was it correct to say that the volumes of water displaced and of liquid displaced were equal?

EXPERIMENT 11

To demonstrate the Principle of Flotation. (REF. SEC. I:12)

Apparatus

Balance, paraffined wooden block, overflow can and catch bucket, water, other liquids.

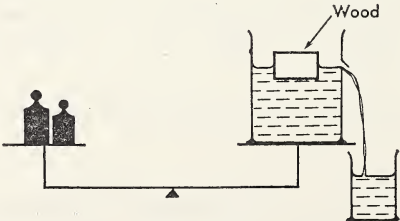


Fig. 6:12

Method

1. Place the overflow can on the pan of the balance. Fill the overflow can to the spout with water (Exp. 8). Balance it.
2. Without adjusting the weights, and after placing the catch bucket under the spout of the overflow can, carefully lower the wooden block into the water. Let it float freely being careful not to let it touch the sides of the can. Note all changes that occur until the water ceases to flow.
3. Repeat this experiment using the other liquids provided.

Observations

Describe the changes in equilibrium that occurred.

Conclusions

1. How does the mass of the floating block compare with the mass of liquid it displaces?
2. State the Principle of Flotation.

Questions

1. Why was the block of wood used in the above experiment coated with a thin film of paraffin?
2. Why does a steel ship float?

EXPERIMENT 12

To show the principle of the hydrometer. (REF. SEC. I:13)

Apparatus

Simple hydrometer (Fig. 4:6), two tall cylindrical vessels, water, other liquids.

Method

1. Float the hydrometer in a cylinder of water, being careful that it does not touch the sides. Note the depth to which it sinks in the water. Calculate the mass of the hydrometer.
2. Rinse the hydrometer in a reserve supply of the liquid to be used. Then float the hydrometer in a cylinder of the liquid, again being careful not to let it touch the sides. Record the depth to which it sinks in the liquid.
3. Repeat part 2 for other liquids.

Observations

1. Depth to which hydrometer sinks in water =
2. Depth to which hydrometer sinks in the liquid =

Calculations

Calculate the specific gravity of the liquid.

Conclusions

1. What is the specific gravity of the liquid?
2. On what principle does the use of the hydrometer depend?

Questions

1. How do you find the mass of the hydrometer?
2. How do you find the mass of the liquid displaced?
3. How is the depth that the hydrometer sinks related to the specific gravity of the liquid?
4. What is the use of the hydrometer?

EXPERIMENT 13

To determine the specific gravity of a liquid using a hydrometer.
(REF. SEC. I:13)

Apparatus

Several tall cylindrical vessels, several liquids (brine, alcohol, etc.), three hydrometers (one for heavy liquids, one for light liquids, one universal).

Method

1. Float an appropriate hydrometer in a cylinder containing the liquid whose specific gravity is to be determined. Be careful not to let it touch the sides of the vessel. Determine the specific gravity by reading the hydrometer scale at the liquid surface level.
2. Repeat for other liquids.

Note This hydrometer method can be used to check the specific gravities of liquids obtained in previous experiments.

Observations

LIQUID	SPECIFIC GRAVITY

Conclusion

State the specific gravity of each liquid used.

Questions

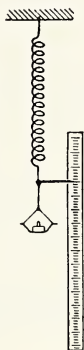
1. Describe the construction of a hydrometer.
2. Why is the lower end of the hydrometer weighted (with mercury or lead shot)?
3. Is the flotation bulb on a hydrometer for low-density liquids larger or smaller than the bulb on a hydrometer for high-density liquids? Explain.
4. Why is the hydrometer scale graduated with the smallest readings at the top and the largest at the bottom? Explain.

EXPERIMENT 14

To illustrate the measurement of force using a stretched spring, or to demonstrate Hooke's Law. (REF. SEC. I:16)

Apparatus

Hooke's Law apparatus, or coiled spring with pointer fixed to one end, set of weights, metre stick.



Courtesy W. M. Welsh Mfg. Co. Chicago

Fig. 6:13

Method

1. Set up the Hooke's Law apparatus as shown, or suspend the spring in a vertical position. Fasten a pan to the lower end of the spring to receive the weights, and a pointer to indicate readings on a scale (metre stick) that is supported parallel to the spring.
2. With your eye level with the pointer, note and record its level on the scale. This is called the zero reading and must be subtracted from each of the other readings that are taken.
3. Add a known weight to the pan. The size of the weight used will depend upon the strength of the spring, but it should be sufficient to cause a 2 or 3 cm. elongation in the spring. Carefully note and record the level of the pointer on the scale. Determine the extension produced.
4. Continue to add known weights, one at a time, reading the scale each time, until about 10 readings have been taken. Each time record the total weight, and the scale reading, and determine the total extension produced.
5. Calculate the extension produced by each gram of load for each case.

Observations

Obs. No.	Total Weight or Stretching Force gm.	Scale Reading cm.	Total Extension cm.	Extension per gram of load cm.
		Zero Reading	—	—
1				
2				
etc.				

Conclusion

1. What is true of the extension of a coiled spring for equal increases in force acting upon it?
2. State Hooke's Law.

Questions

1. The spring balance (Fig. 5:2) is a practical application of Hooke's Law. Why would it be correct to say that a spring balance is used to determine the weight of an object, whereas a beam balance (Fig. 6:3) is used to determine the mass of an object?
2. Which of the above balances could be used to determine the variation in the weight of an object at different positions on the earth's surface? Where would this weight be greater, at the equator or at the North Pole? Explain fully.
3. Plot a graph of your data, using total weights as abscissae (horizontal axis) and the total elongations as ordinates (vertical axis). Does the line produced illustrate Hooke's Law?

EXPERIMENT 15

To study the purpose of a simple machine (the Inclined Plane) and to determine its efficiency. (REF. SEC. I:21)

Apparatus

Inclined plane, car, string, pan, weights, balance, sand.

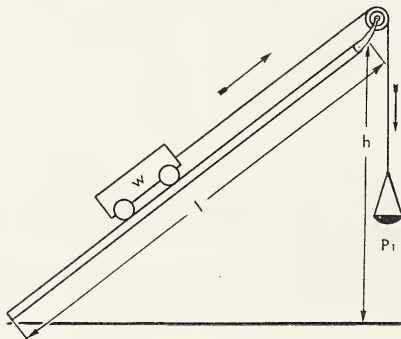


Fig. 6:14

Method

1. Set up the inclined plane as shown in the diagram. Measure the length (l) of the board, and the height (h) of the under side of the elevated end.
2. Determine the mass of the car (W). Attach a pan to string over

pulley and to the car. Adjust so that when the car is placed on the inclined plane, the string is parallel to the inclined plane. Why is this necessary?

3. Add weights to the pan until the car just moves up the plane without acceleration. Fine adjustments may be made by addition of sand if necessary. Determine the mass of the pan plus its contents (P_1).
4. Lighten the contents of the pan until the car just moves down the plane. Determine the mass of the pan plus contents (P_2). The average of these two forces $\left(\frac{P_1 + P_2}{2} \right)$ is the force (F) required to balance the car if there is no friction. Why does this eliminate friction from the calculation?
5. Calculate the work done (input = $F \times l$) and the work obtained (output = $W \times h$).
6. Add additional weights to the car and repeat the above.
7. Raise or lower the end of the plane, thus changing " h ", and repeat for several more readings.

Observations

Obs. No.	Mass of car and contents W gm.	Height h cm.	Output (useful work obtained) Wh gm.cm.	Up Force P_1 gm.	Down Force P_2 gm.	Force $F = \frac{P_1 + P_2}{2}$	Length l cm.	Input (Actual work done) $P_1 l$ gm. cm.
1								
2								
etc.								

Conclusion

1. If friction is eliminated, what do you observe to be true of the work output and the work input.
2. What is meant by the efficiency of a machine (Sec. I:21). Considering the true work input, including friction, to be $P_1 l$, calculate the efficiency of this machine?

Questions

1. Why was it necessary to adjust the apparatus so that the string attaching the pan to the car was parallel to the inclined plane?
2. What is the cause of friction? Why did taking the average of the up and down forces in the above experiment eliminate friction from our calculations?
3. (a) Did changing the slope of the inclined plane change its efficiency?
(b) Did increasing the weight in the car change the efficiency of the inclined plane?
4. What is meant by the "mechanical advantage" of a machine? (See Glossary.) What was the mechanical advantage of our inclined plane?
5. Name several different types of machines and give a practical application for each one.

UNIT II

LIGHT



Wheeler Newspaper Syndicate

These Searchlights Create an Interesting Construction, Showing both a Converging and a Diverging Pencil of Light Rays.

II : 1 NATURE OF LIGHT

Light is that agency which affects the eye and produces the sensation of "seeing" (sight). That branch of physics that covers all the phenomena pertaining to light is called **Optics** (Greek, *ops*—eye). Some knowledge of light existed from very early times, though this was limited primarily to effects rather than to any fundamental understanding.

As to the nature of light, the early Greeks believed it to consist of streams of minute particles of some sort. There was considerable debate as to whether these particles originated in the eye or in the object viewed. Plato (428-348 B.C.) and Euclid (about 300 B.C.) held to the idea that invisible feelers were emitted from the eye, and that the eye sees a body somewhat as the hand may feel it with a rod. The Pythagoreans, Aristotle (284-322 B.C.) in particular, opposed this view and taught that light consisted of minute particles projected into the eye from the object. Both these conflicting ideas were mere guesses and as such were worthless. However, in the eleventh century Alhazen, an Arabian physicist, provided definite evidence

showing that the cause of vision proceeded from the object and not the eye. Even to-day, much mystery still surrounds the nature of light (Sec. II: 7). In view of the fact that light can be produced from other forms of energy, e.g., heat energy, and that light can be transformed into other forms of energy, e.g., electricity, we shall simply say that **light is a form of energy.**

II : 2 SOURCES OF LIGHT

Few objects give out light and these are termed **luminous bodies**. Most objects are non-luminous, becoming visible only when they reflect light from some outside source to our eyes (Fig. 7:1).

Our main source of light is the sun. When we think how important the sun has always been in human affairs, it is not surprising that in prehistoric times it became a prime object of worship. History records the ancient Egyptian Sun-god, Ra, and an ancient Persian god of light, Ahura-mazda. The terms "ray" of light, and "mazda" lamps are derived from these names.

Many objects are rendered luminous by being heated to incandescence. This may be accomplished by mechanical means as shown when sparks are produced by friction between flint and steel in a gas-lighter; by resistance to an electric current in the thin wire used in electric-light bulbs; and by chemical action as in the burning of a fuel. Some objects are luminous at ordinary tem-



Tigerstedt Studios, Calgary

Fig. 7:1 Self-Luminous and Non-Luminous Objects.

peratures, a stick of phosphorus, for example, and fluorescent bodies. Then there is the glow produced by the discharge of electricity through certain gases, e.g., neon tubes. Another interesting example of "cold light" is that produced by fireflies, and by certain deep-sea fish. Probably such light is produced by chemical means.

II : 3 TRANSMISSION OF LIGHT

Unlike sound, light does not require a material medium for its transmission. Evidence in support of this is supplied by the fact that light travels through a vacuum in coming to us from objects in space, and from the glowing filament of an evacuated tube.

Various media differ in their ability to transmit light. Transparent objects such as air, glass and water transmit light so readily that it is easy to see through them. A translucent substance, such as frosted glass or oiled paper, is one that transmits some light, but in

doing so distorts or scatters the light so that we cannot see clearly objects on the other side. Opaque substances, like wood, do not transmit light at all and hence we cannot see through them.

It is common knowledge that light travels in straight lines. Our inability to see around corners, the formation of shadows, and other examples point to this conclusion. This behaviour of light is termed **rectilinear propagation**. Knowing this, we represent a path of light by a straight line called a **ray**. (Note: the light that travels along this path is also called a ray.) The direction in which the light is travelling is indicated by arrow-heads placed on the rays. Several parallel rays form a **beam** of light. Rays of light proceeding towards a point form a **converging pencil**; when they spread out from a point they form a **diverging pencil** (Fig. 7:2).

II : 4 PIN-HOLE CAMERA

The pin-hole camera is an interesting

Glass bricks are used in the construction of many modern buildings. What are the advantages?



Canadian Pittsburgh Industries Ltd.

application of the rectilinear propagation of light. It consists of an opaque box, having a small hole (pin-hole) in the middle of one end, and a translucent screen (piece of ground glass, or oiled

paper) at the other. If a lighted candle is placed a little distance in front of the pin-hole, an inverted image of the candle will be seen on the translucent screen.

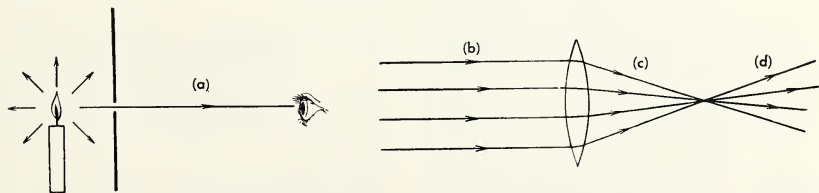


Fig. 7:2 Rectilinear Propagation of Light (a) Ray (b) Beam (c) Converging Pencil. (d) Diverging Pencil.

This kind of image is formed as a result of very narrow diverging pencils of light from each point of the object passing through the pin-hole, and producing small patches of light, identical in shape to the pin-hole, on the screen.

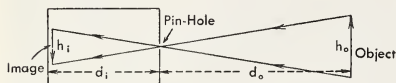


Fig. 7:3 The Pin-Hole Camera.

The resulting image is formed by a large number of these overlapping patches of light, producing an exact replica of the original object. Such an image is a real image. The image so obtained will have a somewhat blurred, or out-of-focus appearance due to the circular edges of each patch of light not entirely overlapping. The larger the pin-hole the brighter will be the image on the screen, but the more blurred will be its edges. The image is inverted because the light rays cross at the pin-hole (Fig. 7:3).

The size of the image is governed by the size of the object, its distance from the camera, and the distance of the image from the pin-hole (Chap. 13, Exp. 1).

$$\frac{\text{Size of Image}}{\text{Size of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

A consideration of the equiangular (or similar) triangles formed by the rays of light as shown in Fig. 7:3 should establish these relationships fairly readily.

If we replace the translucent screen with a light-sensitive paper, or photographic plate, quite acceptable photographs of distant objects can be obtained. A very long exposure is necessary,

however, because of the small amount of light admitted through the pin-hole.

II: 5 SHADOWS AND ECLIPSES

A shadow is the dark space behind an opaque object, an area from which light has been partially or completely excluded. An opaque object in front of a point source of light will cut off all the light, and a sharply defined shadow is produced. If the light comes from a larger source, the shadow will vary in intensity, the dark central portion of the shadow which receives no light from any part of the source being the **umbra** (Fig. 7:4a), the lighter shadow surrounding the umbra which receives some light being the **penumbra** (Fig. 7:4b).

An eclipse of the sun is an interesting shadow phenomenon caused when the moon comes between the sun and earth (Fig. 7:5). A person located in the moon's umbra will observe a **total** eclipse of the sun. If in the moon's

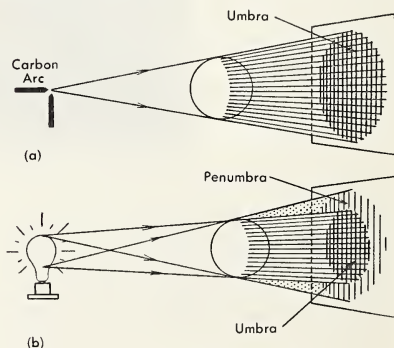


Fig. 7:4 Shadows (a) Using Point Source.
(b) Using Large Source.

penumbra, he will be able to see part of the sun. The latter is called a **partial** eclipse of the sun. Because the moon's orbit around the earth is slightly elliptical its distance from the earth varies. Thus it occasionally happens

that the moon comes between the sun and the earth at a time when its umbra does not reach the surface of the earth. A person located on the earth below the tip of the moon's umbra would see a ring of the sun around the edge of the moon. Such an eclipse is called an **annular eclipse** of the sun and occurs very rarely.

Eclipses of the moon also occur, and at fairly frequent intervals. The moon is a non-luminous body, and is seen only when sunlight is reflected from its surface to the earth. The full moon occurs when the moon is on the opposite side of the earth from the sun. At such a time the moon may pass through the earth's shadow and be eclipsed. A partial eclipse of the moon is caused when it

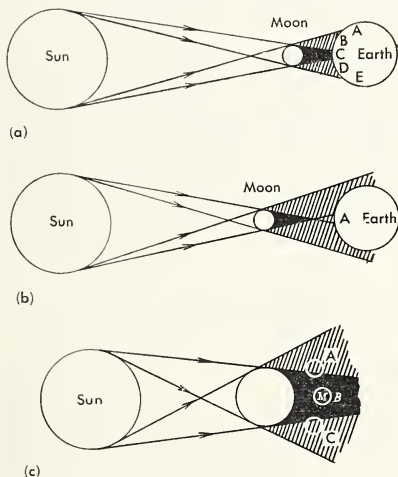


Fig. 7:5 Eclipses.

- (a) Total and Partial Eclipse of the Sun.
- (b) Annular Eclipse of the Sun.
- (c) Eclipse of the Moon.

is partly in the earth's umbra, and a total eclipse when it is completely in the earth's umbra. When in the earth's

penumbra, the moon is not eclipsed, but only less bright as it receives, and hence reflects, less light from the sun.

II:6 VELOCITY OF LIGHT

It has long been suspected that light travels with a finite velocity, but early attempts to measure this velocity were

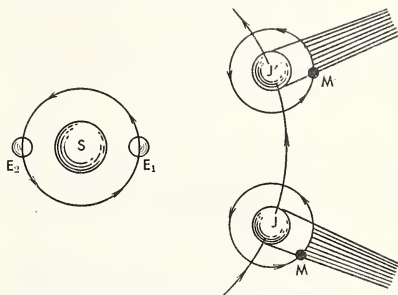


Fig. 7:6 Velocity of Light Using the Moons of Jupiter.

too crude to be successful. The first reasonably accurate value was obtained by a young Danish astronomer Olaus Römer in 1676. He found that intervals between the successive eclipses of one of the moons of the planet Jupiter were longer when Earth was receding from Jupiter (going from E_1 to E_2) and shorter when Earth was approaching (going from E_2 to E_1 , Fig. 7:6). Römer ascribed the discrepancy to the time required for light to travel across the diameter of the earth's orbit. The time-lag was found to be about 16.5 minutes or approximately 1000 seconds. Since the diameter of the earth's orbit is about 186,000,000 miles, the velocity of light is found to be 186,000 miles per second.

The first determination of the velocity of light over short distances on the earth was made in 1849 by A. H. Fizeau. His method was to pass a beam of light through one of the gaps in a toothed wheel, and reflect it back on its path from a mirror three or four miles away

(Fig. 7:7). When the wheel was at rest, the return beam passed back through the same gap and was visible on the other side. When the wheel was rotated rapidly, a speed could be found at which

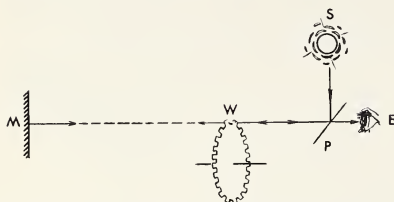


Fig. 7:7 Scheme of Fizeau's Apparatus for Measuring Velocity of Light.

the return way was blocked by the next tooth. The time spent by the wheel in spinning through this small part of a revolution, is also the time required for the light to travel to the distant mirror and back again. Hence, knowing these facts, the velocity of light could be easily calculated.

A better method was devised by J. L. Foucault in 1850, who used a rotating

mirror instead of a toothed wheel. This method was used in more elaborate form by A. A. Michelson in 1926, with an eight-sided mirror and a considerably increased light path (Fig. 7:8). More recently, Michelson in collaboration with others, set up a mile-long evacuated tube with a mirror arrangement for causing a beam of light to traverse this path back and forth many times before being observed. Again using a rotating-mirror method, they obtained a quite accurate value for the velocity of light in a vacuum which was found to be slightly higher than its velocity in air.

The approximate values for the velocity of light, C , in air are:

$C = 300,000$ kilometres per second or
 3×10^{10} centimetres per second
 or $C = 186,000$ miles per second.

The velocity of light is a most important physical determination, since it is the speed with which many forms of energy travel through space. It is interesting to note that the vast distances of space are measured in terms of the light-year. This is the distance travelled

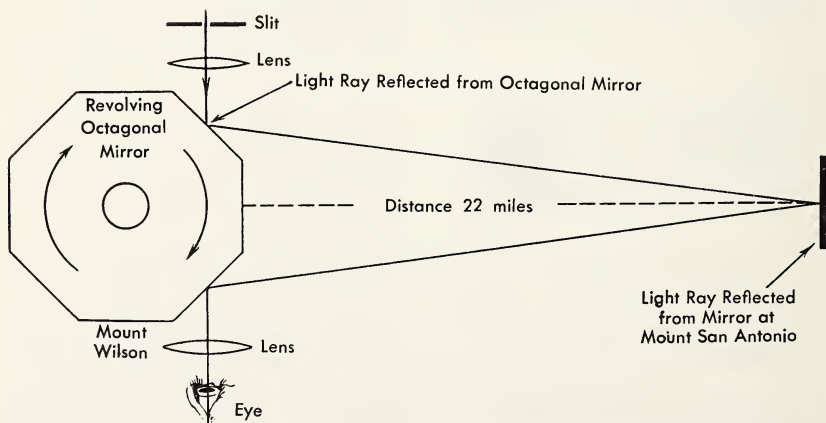


Fig. 7:8 Velocity of Light, Michelson's Method.

by light in one year. Some of the more distant stars and nebulae are so remote from the earth that the light by which we now see them set out on its journey to the earth thousands of years ago.

II : 7 THEORIES OF LIGHT

The first rational attempt to explain the propagation of light was made by Sir Isaac Newton (1642-1728). His theory, the **Emission or Corpuscular Theory**, postulated that light energy was conveyed through space by a swiftly moving stream of particles or corpuscles shot out from the luminous body. Most of the properties of light known at Newton's time such as the rectilinear propagation of light and the effects of reflection (Chap. 9) and of refraction (Chap. 10) were adequately accounted for by this theory.

A rival postulate was put forward by Christian Huygens (1629-1695), the son of a Dutch diplomat and poet. He sought to explain the behaviour of light in terms of waves, and hence his theory is called the **Wave Theory**. Again, reflection and refraction were readily explicable in terms of this wave theory. Difficulties were encountered, however, when seeking to explain the rectilinear propagation of light, and also in the need for postulating the existence of a medium, the ether, completely filling space in which the waves could travel. As a result, the wave theory remained undeveloped and Newton's corpuscular theory was generally accepted.

Early in the nineteenth century, Thomas Young (1773-1829), and A. J.

Fresnel (1788-1827), provided valuable experimental support for the wave theory of light. They were able to show that two beams of light could be made to interfere with and to reinforce each other, thereby producing alternate dark and bright lines. This could only be explained by "superposition of waves". At one position when in opposite phase, a crest with a trough, these waves produce a dark line. At another position when in the same phase, a crest with a crest, or a trough with a trough, they produce a bright line.

Another line of experimental support in favour of the wave theory was to show that the velocity of light is smaller in the denser of two media. The corpuscular theory had predicted the exact reverse of this.

Recent work seems to favour a combination of the corpuscular and wave theories in the explanation of many of the observed effects. This theory called the **Quantum Theory**, was first devised by Max Planck in 1901. According to this theory, light is emitted by the atoms of a luminous body in separate packets or bundles of energy called quanta or photons. Probably one or more of the electrons revolving about the nucleus of an atom can be made to jump from one orbit or "energy level" to another. As they do so, one or more quanta of energy, or photons are emitted. This energy radiates from the luminous body as electromagnetic waves (Sec. II:38). The energy content of a photon determines the length and frequency of the wave, and hence the colour of the light observed.

II : 8

QUESTIONS

A

1. (a) Define optics.
(b) What is the nature of light?
2. (a) Distinguish between "luminous" and "illuminated" objects.
(b) How may objects be rendered luminous?
3. (a) What evidence have we to prove that light can travel through a vacuum?
(b) Distinguish between opaque, translucent and transparent substances. Give examples of each.
4. (a) What is meant by the "rectilinear propagation of light"? Discuss evidence in support of it.
(b) Define: ray, beam, converging pencil, diverging pencil.
5. (a) Describe the image obtained in a pin-hole camera.
(b) Explain how it is produced.
(c) Name three factors that govern its size.
(d) The length of a pin-hole camera is 10 in. An object 6 ft. high is placed at a distance of 30 ft. from the pin-hole. Calculate the size of the image produced.
6. (a) Define: umbra, penumbra.
(b) Construct a labelled diagram to show how both total and partial eclipses of the sun are produced.
7. (a) What is the velocity of light in air?

(b) How many minutes are required for light to travel from the sun to the earth (93×10^6 miles)?

(c) What is a light-year?

8. What contributions did Newton, Huygens and Planck make to a theory of light?

B

1. Calculate the distance of an object 12 ft. high whose image is 4 in. high in a pin-hole camera 10 in. long.
2. Calculate the size of the image of a tree 30 ft. high, 100 yards distant, in a pin-hole camera 8 in. long.
3. Calculate the height of a building 300 metres distant which produces an image 2.5 cm. high in a pin-hole camera 2.0 in. long.
4. How long does it take for light to travel from the moon to the earth (24×10^4 miles)?
5. Calculate the number of (a) miles, (b) kilometres in 1 light-year.
6. Sirius, the brightest star in the sky, is 9 light-years away. How far away is this in miles?
7. Our nearest neighbour among the stars, excepting the sun, is Proxima Centauri which is about 25×10^{12} miles away. How long does it take for light from this star to reach us?

II : 9 INTRODUCTION

In the preceding chapter we studied the sources of light and the transmission of light. We noticed that in order to give out light objects must be either luminous or illuminated. In our everyday life we are not too concerned about the nature of light or its velocity, but in its illuminating power.

A student in the study hall may complain that the lighting is poor although the lights in use are actually powerful. The powerful lights may be at too great a distance from the reading material. Actually, the student is not complaining about the illuminating power, but the intensity of illumination. We must distinguish clearly between the two. Illuminating power refers to the quantity of light thrown out at any instant and depends only on the source of light. Intensity of illumination depends not only on the strength of the source of light, but also on its position.

II : 10 ILLUMINATING POWER

(a) *The Standard Candle*

The **illuminating power** of a source of light means the rate at which energy

in the form of light is being emitted by that source. In practice, it is measured in standard candles. A **standard candle** was defined by an Act of Parliament passed in 1860 as a candle made of sperm wax weighing one-sixth of a pound, and burning at a rate of 120 grains per hour.

Actually the standard candle is not a very satisfactory unit, for its illuminating power varies slightly according to the shape of the wick, the pressure and humidity of the air and other circumstances. In practice it is more convenient to use incandescent lamps which have been rated by comparison with the standard.

Incandescent lamps used for interior lighting generally have an intensity ranging from a few candles to several hundred candles. A 40-watt lamp has an intensity of about 35 candlepower. The intensity of a 100-watt lamp is about 130 candlepower. A good incandescent gas mantle has about 96 candlepower.

We must not confuse candlepower with brightness. Suppose an incandescent gas mantle and an acetylene flame are of equal candlepower but the surface area of the mantle is ten times as great as the surface area of the acetylene flame. The acetylene flame would be much more dazzling to look at than the mantle, because the amount of light given off per unit of surface area is ten times as great. Thus we see that brightness is determined by the amount of light given off per unit area. That is why the modern electric lamp filament is

so often enclosed in translucent instead of transparent glass (SEC. II:3).

(b) The Lumen

A lamp is thought of as sending out a luminous flux, which means a flow of light. Lamps do not emit light equally in all directions, so that candlepower varies with direction. Engineers prefer to express light outputs in lumens. A **lumen** is the luminous flux or the rate of flow of light energy through unit surface at unit distance from a 1-candlepower source. To understand the relationship between candlepower and lumens, place a standard "point" candle at the centre of a hollow sphere of 1-ft. radius with black walls, and let there be an opening in it 1 square foot in area (Fig. 8:1). Then the light passes through the window at the rate of 1 lumen. Moreover, the area of the entire sphere is 4π square feet, so that the candle emits light in all directions at the rate of 4π lumens.

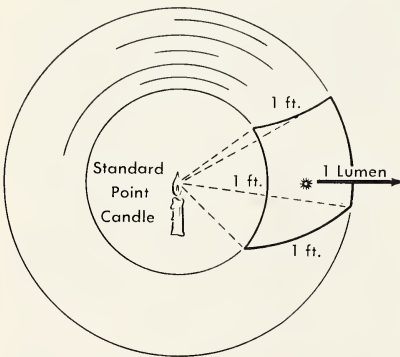


Fig. 8:1 To Illustrate the Meaning of a Lumen.

If a lamp were fitted with a perfect reflector, the number of lumens would be unchanged but the light distribution would be modified. The mirror of an

automobile headlight concentrates the light into a narrow cone and increases the apparent candlepower in a certain direction. However, it does not increase the number of lumens emitted by the lamp.

II: 11 LAW OF INVERSE SQUARES

In section II:9 we noted that the intensity of illumination depends not only on the strength of the source of light, but also on its distance from the source. In order to study the variation of illumination with distance from a small "point" source, consider three parallel rectangular screens (Fig. 8:2) so

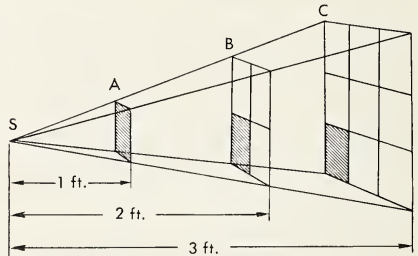


Fig. 8:2 To Illustrate the Law of Inverse Squares. The illumination at A is four times that at B and nine times that at C.

placed that A, with an area of just 1 square foot, is exactly 1 foot from the light source S; and B, which is four times as large, is placed 2 feet from S; and C, which has nine times the area of screen A, is placed 3 feet from S. Screens B and C are both completely shaded by screen A. When screen A is removed, those rays of light which illuminated A fall upon screen B. But B has an area of 4 square feet while the area of A is only 1 square foot. Consequently, each square foot of surface at B, 2 feet from the light source, can receive only one-fourth as much light as a square foot at

surface A, only 1 foot distant. Likewise, C is three times as far away as A, and the light will be spread over nine times as much area. Thus 1 square foot of surface will receive only one-ninth as much light at C as at A.

The conclusion thus reached is known as the **Law of Inverse Squares** and may be stated as follows: **The intensity of illumination of a surface varies inversely as the square of its distance from the source of light.**

II: 12 INTENSITY OF ILLUMINATION

Since the intensity of illumination depends upon two factors:

- (i) distance from the source and
- (ii) illuminating power,

the illumination is usually expressed in foot-candles. A **foot-candle** is the intensity of illumination at a distance of 1 foot from a light source of 1 candlepower.

Thus, while the intensity of illumination due to a standard candle at a distance of 1 foot is 1 foot-candle (by definition), at 2 ft. the intensity is only 1/4 ft.-candle, at 3 ft. 1/9 ft.-candle and so on. If we use two candles, the intensities (in foot-candles) would be respectively 2, 1/2 and 2/9.

Considering both distance and the source, the illumination (E) is equal to the intensity of the source (I) divided by the square of the distance (d) from the source. In equation form we can write:

Illumination =

$$\frac{\text{Intensity of source}}{\text{Square of its distance from source}}$$

or

$$E = \frac{I}{d^2}$$

Example

What illumination will be provided on a surface 3 ft. from a 120-candlepower lamp?

$$\begin{aligned} E &= ? \text{ foot-candles} \\ I &= 120 \text{ candlepower} \\ d &= 3 \text{ ft.} \end{aligned} \quad E = \frac{I}{d^2} = \frac{120}{(3)^2} = 13.3$$

∴ The illumination is 13.3 foot-candles.

A more modern unit for the measurement of illumination is the **lumen per square foot** which is equivalent to one foot-candle. The amount of illumination on a surface 1 foot from a 1-candlepower source is 1 lumen per square foot. A surface 1 foot from a lamp with an intensity of 20 candlepower, receives 20 lumens per sq. ft. of illumination. If it is held 2 feet from such a lamp, it receives only 5 lumens per sq. ft.

Example

If the distance from a 64-candlepower lamp to a book is 4 ft., find the illumination of the book expressed in lumens per square foot and in foot-candles.

$$\begin{aligned} E &= ? \\ I &= 64 \text{ c.p.} \\ d &= 4 \text{ ft.} \end{aligned} \quad \begin{aligned} E &= \frac{I}{d^2} \\ E &= \frac{64}{(4)^2} = 4 \end{aligned}$$

∴ The illumination is 4 lumens per sq. ft. or 4 foot-candles.

Since the standard candle emits light in all directions at the rate of 4π lumens (Sec. II:10), then 64 candles emit 256π lumens in all directions. At a distance of 4 feet the total illuminated area is 64π square feet (Sec. II:10(b)). That is, the illumination is $(256\pi \div 64\pi)$ 4.0 lumens per square foot. Engineers are more often interested in the number of lumens of light which fall on a given area. This is equal to the illumination times the area. In equation form

$$\text{Lumens} = \text{foot-candles} \times \text{square feet}$$

TABLE OF ILLUMINATION INTENSITIES

	Foot-Candles
Noon sunlight	5,000-10,000
Bright moonlight	0.025
Needed for baseball and football	30-50
Needed for street lighting	0.05-0.25
Desirable values for reading	15-25

II: 13 THE IMPORTANCE OF PROPER ILLUMINATION

A century ago, little reading was done by artificial illumination. For this there were several reasons, among them being the scarcity of books and newspapers, the small amount of leisure, and the lack of adequate light sources. Today the output of printing presses is tremendous, modern machinery replaces labour providing greater leisure, and the electric lamp affords illumination which, if wisely used, would be beyond reproach. Unfortunately, in some schools and homes lighting conditions merit severe condemnation. Often a student seated in some corner receives too little light. In many places unshaded lamps or brightly painted walls reflect light into the eyes and cause "glares" which are very harmful.

For satisfactory lighting home lamps should fulfil three conditions:

- (1) they should furnish the proper illumination
- (2) they should be so designed and placed as to give diffused light, and
- (3) they should be relatively large sources.

The recent trend toward indirect lighting has improved conditions of illumination in the home. The fluorescent lamp produces a light that is diffused and has little glare because of its large surface area.

Lighting companies now use photoelectric cells, which read directly in foot-

candles, to check the illumination in buildings. Such an instrument (Fig. 8:3) provides a simple and easy method to



Central Scientific Co.

Fig. 8:3 A Photoelectric Light Meter.

determine how large a lamp should be used in a particular place.

II: 14 PHOTOMETERS

We measure the candlepower of any light source by comparing its intensity with that of a standard light source. The instrument used is called a **photometer**. The luminous intensities of two sources may be compared by placing them in such a manner that they produce equal illuminations at adjoining surfaces.

(1) *The Bunsen or Grease-Spot Photometer.* Put a small drop of oil on a sheet of white paper, and look at a source of light through the oiled spot. The spot looks brighter than the surrounding paper because it transmits more light. Now look at the paper from the same side as the light. The spot appears

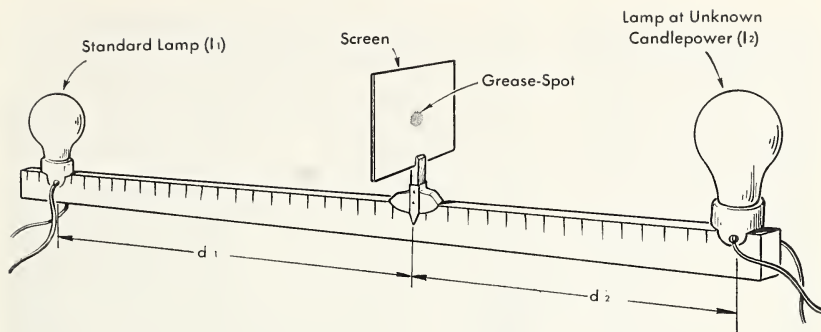


Fig. 8:4 A Bunsen or Grease-Spot Photometer.

darker than the surrounding paper because it transmits more light and reflects less. If the oiled spot is equally illuminated from both sides, it appears equally bright on both sides.

The Bunsen photometer (Fig. 8:4) consists of a grease-spot screen placed on a metre stick between a standard lamp and the lamp of unknown candlepower. The screen is moved back and forth along the metre stick until it is equally illuminated on both sides. At this point the grease spot practically disappears. When the screen is properly adjusted, we measure the distance from

the standard lamp to the screen, and the distance from the lamp of unknown intensity to the screen. The intensities of the two light sources, in candlepower, are directly proportional to the squares of their distances from the screen.

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

where I_1 is the standard intensity;
 d_1 is the distance of screen from standard lamp

I_2 is the unknown intensity and
 d_2 is the distance of screen from unknown lamp.

Example

A lamp with an intensity of 40 candlepower is used as a standard on a Bunsen photometer. The screen is equally illuminated when it is 20 cm. from the standard lamp and 80 cm. from the lamp of unknown intensity. Find the intensity of the unknown lamp.

$I_1 = 40$ candlepower

$d_1 = 20$ cm.

$I_2 = ?$

$d_2 = 80$ cm.

$$\begin{aligned} \frac{I_1}{d_1^2} &= \frac{I_2}{d_2^2} \\ \frac{40}{(20)^2} &= \frac{I_2}{(80)^2} \\ I_2 &= \frac{40 \times (80)^2}{(20)^2} = 640 \end{aligned}$$

$\therefore$ the intensity of the unknown lamp is 640 candlepower.

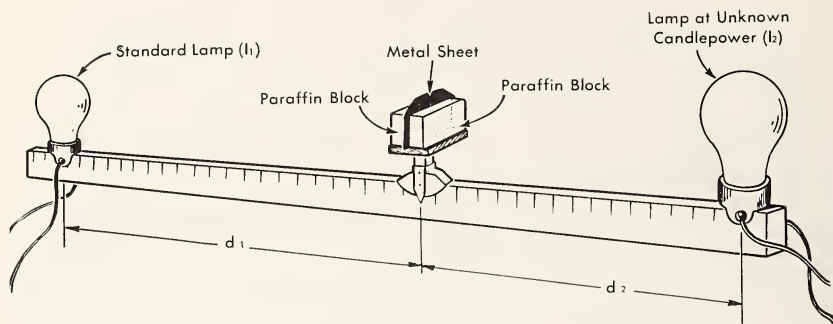


Fig. 8:5 A Joly Photometer.

(2) *Joly Photometer.* This is another simple photometer. It consists of two blocks of paraffin separated by a thin sheet of metal foil (Fig. 8:5).

The light from either side is trans-

mitted by the paraffin, but is stopped by the metal. By looking at the edges of the blocks of paraffin it is easy to adjust the photometer so that both sides are equally illuminated. The distances of the lamps

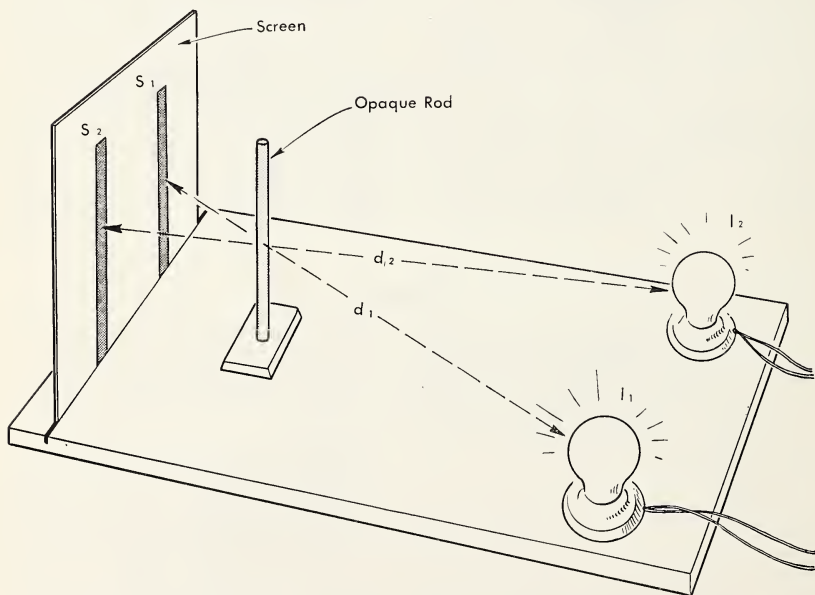


Fig. 8:6 Rumford Shadow Photometer.



Ontario Hydro

Fig. 8:7 A Spherical Photometer.

are then measured and calculations made in the same manner as with the Bunsen photometer.

(3) *Rumford Shadow Photometer*. This simple photometer consists of a vertical screen and a vertical opaque rod in front of the screen (Fig. 8:6).

The light from the standard lamp and the lamp of unknown candlepower will cause the rod to cast shadows on the screen. Move the lamps back and forth until the two shadows are equally illuminated. The shadow S_2 is illuminated by light I_1 and the shadow S_1 is illuminated by light I_2 . The distances of the lamps

from the shadows they illuminate are then measured and calculations made in the same manner as with the other mentioned photometers.

(4) *Spherical photometer*. This is a more accurate photometer and is used commercially. The lamp to be tested is placed in the centre of a large sphere which is painted white on the inside (Fig. 8:7). The intensity of the light transmitted through a window is measured by means of a photoelectric cell. The more intense the light the stronger the current which flows through the photoelectric cell.

II:15

QUESTIONS

A

1. Distinguish between luminous and illuminated objects.
2. Define a standard candle.
3. Discuss the factors determining the amount of illumination received at a point on a screen.

4. In what unit do we measure the intensity of a light source? Define it.

5. In what unit do we measure illumination? Define it.

6. Distinguish between a foot-candle and a lumen. What advantage has the latter?

7. Discuss the effect of a reflector on (a) candlepower and (b) light output.

8. (a) What is the purpose of a photometer?

(b) Why should unglazed paper be used in making a Bunsen photometer?

9. Find out how a Conroy photometer is made.

10. What is the principle of a photoelectric cell? State some uses of the photoelectric cell.

B

1. Find the illumination, in ft.-candles, on a table surface 4 ft. below an 8-candle source.

2. Find the intensity of a source which provides illumination of 10 ft.-candles at a distance of 5 ft.

3. When a book is held at a distance of 2 ft. from a lamp, the illumination is 8 ft.-candles. Find the illumination at 1 ft. from the lamp.

4. If a photographic print can be made in 14 sec. when held 2 ft. from a lamp, find the correct exposure when it is held 3 ft. away.

5. A book is adequately illuminated when it is 4 ft. from an 80-candle source. Find its illumination when it is moved 6 ft. farther away.

6. A 40-watt incandescent lamp is rated at 0.90 candle per watt. Find its luminous intensity in candles.

7. What is the illumination 4 ft. from a standard candle?

8. What is the illumination 5 ft. from a 100-candle lamp?

9. What candlepower is necessary to produce 10 ft.-candles at a distance of 3 ft.?

10. How far from a 50-candlepower lamp should a screen be placed to have 2 ft.-candles illumination?

11. At what rate, in lumens, does (a) a standard point candle emit light?

(b) a four-candlepower source emit light?

12. What is the illumination 5 ft. from a lamp whose intensity is 150 candles?

13. The amount of illumination thrown on a screen by two sources of light is the same when the distances from the lamps to the screen are 3 ft. and 2 ft. respectively. If the intensity of the first lamp is 20 candles, what is the intensity of the second lamp?

14. It is recommended that the illumination be 25 lumens per square foot for reading. How far from the reading paper should a 200-candle source be placed to provide this illumination?

15. A 100-watt lamp placed at one end of a metre stick and a 10-candle source placed at the other end equally illuminate a photometer which is 75 cm. from the 100-watt lamp. How many candles per watt does the lamp supply?

16. Two lamps of 25 candlepower and 100 candlepower respectively are 9 feet apart. Where must a screen be placed to receive equal illumination from each lamp?

17. What is the luminous intensity of a source which when placed at a distance of 0.50 m. from a point produces at that point illumination equal to that from a 90-candle source at a distance of 3.00 m.?

18. The illumination of noon sunlight in June is about 10,000 ft.-candles. What would be the illumination if instead of being at a distance of 96,000,000 miles, the sun were at the distance of the moon, 240,000 miles?

19. A standard candle and a 4-candle source are 3.0 ft. apart. How far from the standard candle must a screen be placed to be equally illuminated by each source? (There are two answers. Show why, using a diagram.)

20. A man can just read a newspaper at a distance of 20 ft. from a 100-candle-power lamp. At what distance could he just read it using a single candle?

21. A 4-candle point source emits light in all directions. Find

(a) the total illumination, in lumens, on

the inside of a sphere having a radius of 4 ft. if the light source is located at its centre,

(b) the surface area of the sphere,

(c) the illumination, in lumens per square foot.

CHAPTER 9

REFLECTION OF LIGHT— MIRRORS

II: 16 THE LAWS OF REFLECTION

In section II:2, we learned that most objects are made visible when light falling on them is reflected back to our eyes. The rays of light that fall upon a body are called **incident rays**, while those that are sent back by the body are called **reflected rays**.

A **mirror** is a smooth, highly polished surface, designed to reflect a maximum amount of light. Mirrors usually consist of pieces of glass silvered on one surface. Some are flat and are called **plane mirrors**, while others are called

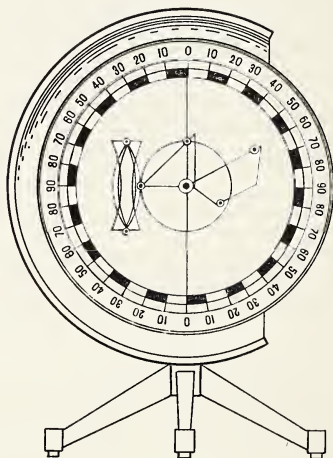


Fig. 9:1 The Optical Disc, for Demonstrating the Laws of Optics.

Reflections on a Lake.



Star Newspaper Service

curved mirrors. However, any smooth surface, such as polished metal, polished wood, or still water, will serve as a mirror.

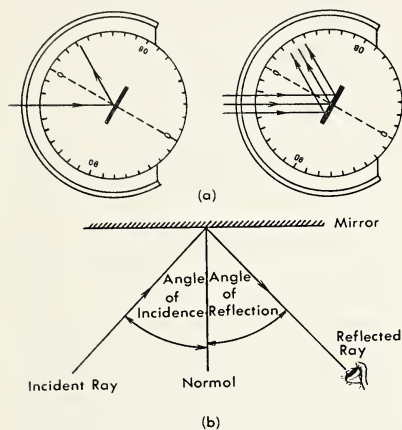


Fig. 9:2 Reflection of Light by a Plane Mirror (a) Using Optical Disc. (b) Terms.

To study reflection of light and other optical phenomena an optical disc is used (Fig. 9:1). This consists of a circular flat disc, graduated in degrees, to which various pieces of optical equipment can be fastened by means of thumb-screws. The disc can be turned about a horizontal axis by means of a handle fastened to the back. Surrounding the disc is an opaque collar in which is a window containing one or more horizontal slits.

Mount a plane mirror at the centre of the disc, with the face of the mirror at right angles to the zero line marked on the disc (Fig. 9:2). Allow a ray of light from a lantern to pass through a single slit in the window of the optical disc so that it falls upon the mirror. Adjust so that the **point of incidence** coincides with the point where the zero line meets the mirror. This line at right

angles to the reflecting surface and meeting it at the point of incidence is called the **normal**. Rotate the disc and thus cause the incident ray to strike the mirror at different angles. In each case note the direction of the reflected ray and compare the size of **angle of incidence** (the angle between the incident ray and the normal), with that of the **angle of reflection** (the angle between the reflected ray and the normal). In each case these two angles will be found to be equal, and the incident ray, the reflected ray and the normal will all be found to be in the plane of the disc. Hence we can state the two laws of reflection as follows:

First Law: The angle of reflection always equals the angle of incidence
or $\angle r = \angle i$

Second Law: The incident ray, the normal, and the reflected ray all lie in the same plane.

These laws are quite simple and straightforward. We apply them daily in games such as handball, tennis and basketball where the bounce of a ball is utilized. Experiment 3, chapter 13, is an alternative method for proving these two laws of reflection.

II: 17 REGULAR AND DIFFUSE REFLECTION

When parallel rays fall upon a smooth reflecting surface, such as a plane mirror, they form the same angle of incidence with the surface, and in consequence they will be reflected as a beam of parallel rays (Fig. 9:3a). Such reflection is called **regular reflection** and often produces undesirable glare. For example, one finds it difficult to read from a glazed paper in sunlight.

Diffuse or irregular reflection occurs

when light strikes a rough surface (Fig. 9:3b). Such a surface may be considered to be composed of a large number of tiny, flat surfaces that face in all directions. Thus when parallel rays of light strike such a surface, the individual rays are scattered or diffused due to their being reflected in different directions.

To avoid glare it is often necessary to promote diffusion of light. Unglazed paper is used for newspapers, and for

light bulbs, and lamp-shades. Prism glass and other types of roughened glass in windows serve the same purpose.

II : 18 IMAGES IN PLANE MIRRORS

Mirrors have many and varied uses. Large plate-glass mirrors are frequently placed on the walls of our homes and of public rooms to give an impression of spaciousness. Rear-view mirrors are now compulsory in all automobiles. Mirrors are often used in scientific instruments to reflect light onto a scale, in projectors to intensify the light beam, in the view-finder of reflex cameras, in periscopes, and the like. In view of such widespread uses, it should be of real interest to us to study the images produced by plane mirrors (Fig. 9:4).

On doing experiment 4, chapter 13, you will learn the following facts about images in plane mirrors:

The Position of the Image. The image is as far behind the mirror as the object is in front, and a line joining the two passes through the mirror at right angles.

The Characteristics of the Image. The image is the same size as the object. It is a virtual image, that is, it only

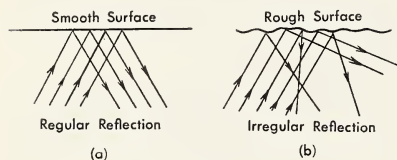


Fig. 9:3 Regular and Diffuse Reflection.

wall-papers. Frequently the woodwork in our homes is left with a dull finish. These, and other devices, all cause diffuse reflection of light.

Diffusion, and hence the elimination of glare, is also obtained by transmission of light through frosted or opalescent

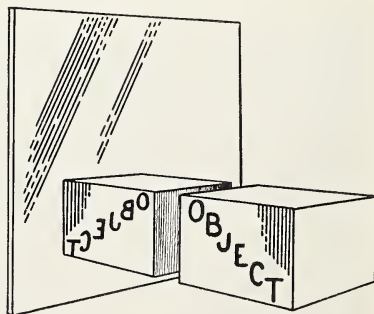
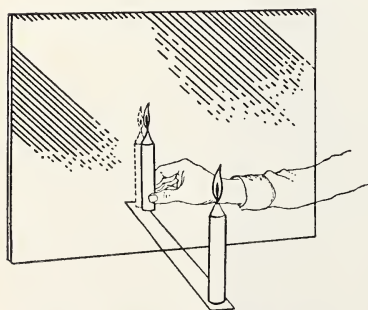


Fig. 9:4 Images in a Plane Mirror (a) The Position and Characteristics of the Image. (b) Lateral Inversion.

appears to be there. No light emanates from it. Such an image cannot be projected onto a screen. The image is vertically erect, but laterally inverted. When we say "laterally inverted" we mean that the right and left sides are interchanged (Fig. 9:4b).

Note that when the mirror is horizontal, the image is vertically as well as laterally inverted. Recall what you observe on looking into a still body of water to verify this fact.

II: 19 TO LOCATE IMAGES IN PLANE MIRRORS

These phenomena observed experimentally can be shown to be true as a geometrical consequence of the laws of reflection, Sec. II:16. Let us consider the simplest possible case, that of a point object, O , the image of which, I , is viewed by an eye BD (Fig. 9:5). O is sending out light rays in all directions.

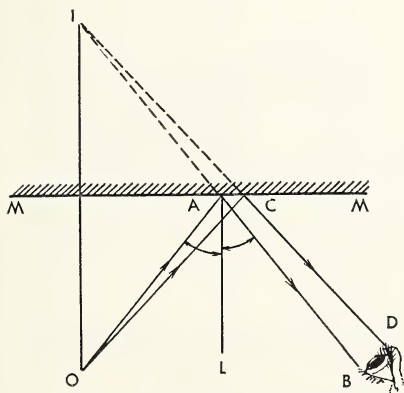


Fig. 9:5 To Locate the Image of a Point in a Plane Mirror.

Only those lying between OAB and OCD enter the pupil of the eye after being reflected from the mirror. The reflected rays AB and CD appear to be

coming from I , their point of intersection.

In order to locate the image of an object in a plane mirror geometrically, the following construction is necessary (Fig. 9:6). From each point of the

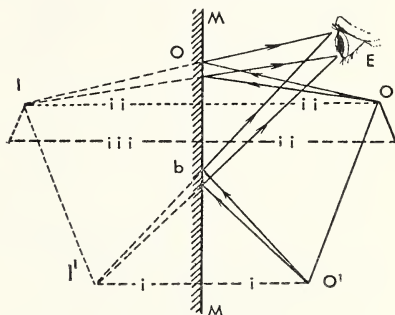


Fig. 9:6 To Locate the Image of an Object in a Plane Mirror.

object, draw a perpendicular to the mirror, and extend it an equal distance behind the mirror. Join the ends of all such lines and you will have an outline of the image of the object. Using the half arrow ($\uparrow$) enables you to indicate lateral inversion nicely. To show how the eye sees the image place a diagram of an eye on the same side of the mirror as the object. Draw a cone of rays from the tip of the image to just fill the pupil of the eye. Draw two light rays from the tip of the object to the two points on the mirror where the previous rays met the mirror. Put arrows on the real light rays as shown. Repeat this same procedure for each point on the object. Thus the eye is receiving light that appears to originate from the virtual image behind the mirror, but actually comes from the object.

In all diagrams, use faint lines for construction, dotted lines for imaginary rays or virtual image, and solid lines for real rays, real image, object, etc.

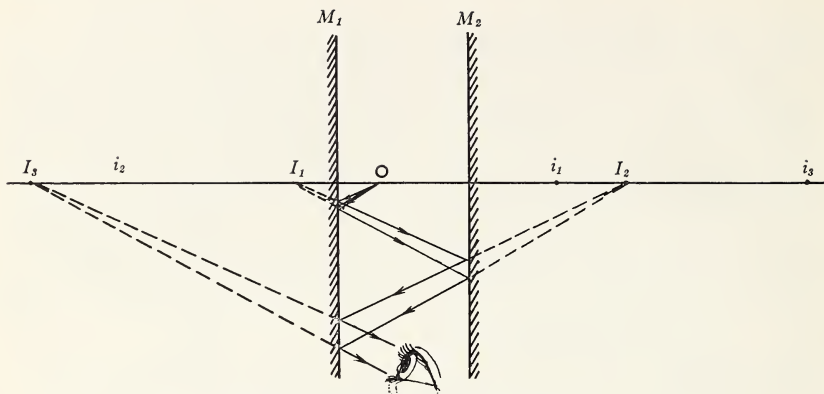


Fig. 9:7 Images in Parallel Mirrors.

II : 20 PLANE MIRROR SYSTEMS

1. Parallel Mirrors

On looking into a mirror facing a parallel mirror on the opposite wall of a room, such as is used in barber shops, a very large number of images of the room can be seen stretching away almost endlessly. To discover how these are formed study Fig. 9:7 carefully.

A series of images representing the side of O facing mirror M_1 are formed (I_1, I_2, I_3) and also a series of images representing the side of O facing mirror M_2 (i_1, i_2, i_3). These multiple images are due to the image formed in one mirror, acting as the object, which in turn forms an image in the second mirror, and so on. Since some light is absorbed at each reflection, each succeeding image is fainter than the one preceding.

2. Mirrors at Right Angles

When two mirrors are placed at right angles to each other (Chap. 13, Exp. 5), three images of an object will be observed (Fig. 9:8). I_1 and I_2 are images of O in mirrors M_1 and M_2 . I_3 is the image of I_1 in the mirror

M_2 produced (M_2 produced is really an image of M_2 in M_1) and of I_2 in mirror M_1 produced, these two images coinciding. How the eye sees these

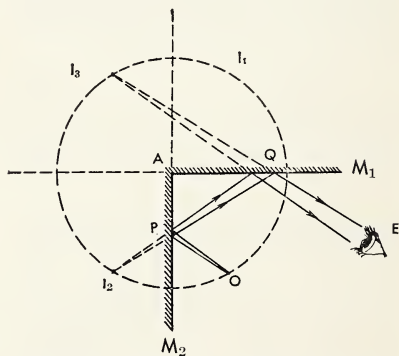


Fig. 9:8 Images in Mirrors at Right Angles.

images may be shown by a construction similar to that used previously.

3. Mirrors Inclined at Sixty Degrees

When mirrors are inclined, the number of images obtained depends upon the

angle between the mirrors. In general we can say:

the number of images

$$= \frac{360}{\angle \text{Inclination}} - 1$$

For example, using mirrors at right angles we obtained three images

$$\left(\frac{360}{90} - 1 = 3 \right).$$

If two mirrors are inclined at 60° , five images will be obtained (Fig. 9:9).

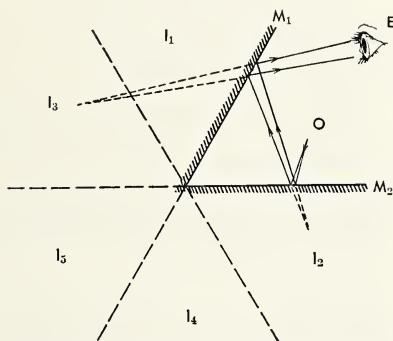


Fig. 9:9 Images in Mirrors Inclined at 60° .

Sir David Brewster, of Edinburgh, making use of the images produced by inclined mirrors, in 1819 invented the kaleidoscope. This consists of three mirrors set at angles of 60° to each other.

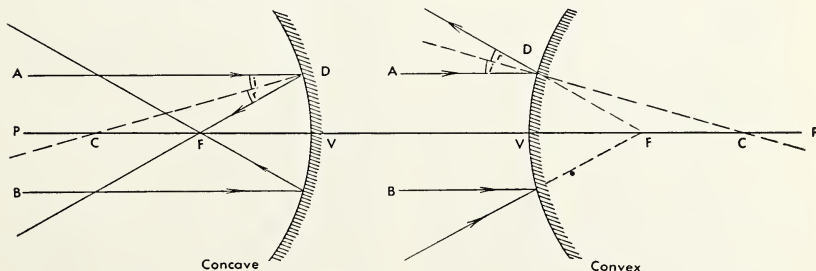


Fig. 9:11 Terms Used with Curved Mirrors.

These form multiple images of differently shaped pieces of coloured glass placed between them. Many beautiful and fascinating designs can be produced at every turn of the instrument.

II:21 CURVED MIRRORS

Curved mirrors are frequently more suitable than plane mirrors for certain purposes. Curved mirrors are used as rear-vision mirrors, as shaving mirrors and as reflectors for car headlights.

One important type of curved mirror is the **spherical mirror** whose reflecting surface is a portion of the surface of a sphere. If the inner surface is the reflecting surface, it is a **concave mirror**; if reflection occurs at the outer surface it is a **convex mirror**. We represent such mirrors in cross-section by the arc of a circle (Fig. 9:10).

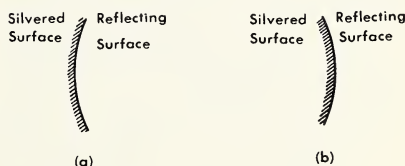


Fig. 9:10 Spherical Mirrors.
(a) Concave or Converging.
(b) Convex or Diverging.

A few terms used in connection with curved mirrors need to be defined (Fig. 9:11):

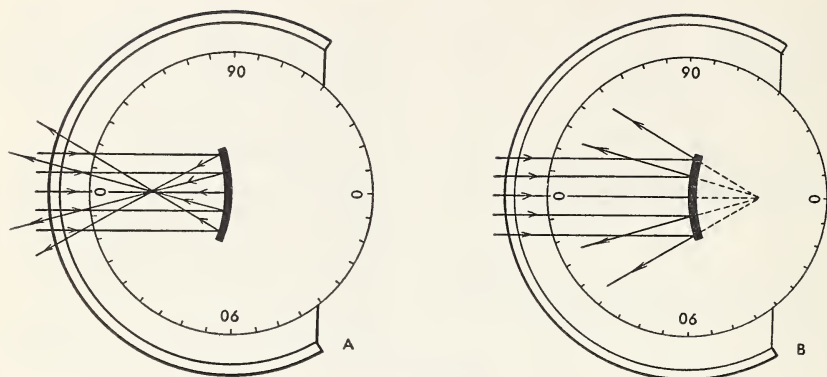


Fig. 9:12 Action of Curved Mirrors. (A) Concave. (B) Convex.

Centre of Curvature, C , is the centre of the imaginary sphere from which the mirror was cut.

Vertex, V , is the mid point of the mirror.

Principal Axis, PV , is the line through the centre of curvature and the vertex of the mirror.

Secondary Axis, CD , is any other line drawn through the centre of curvature to the mirror. Since all radii of a circle meet the circumference at right angles, and since all axes behave like radii since they pass through the centre of curvature, it follows, that a **Normal** to the surface of a curved mirror at the point of incidence is simply a secondary axis.

Principal Focus, F , is the point on the principal axis, through which rays, travelling parallel to the principal axis (and fairly close to it) pass, after being reflected from the mirror. For a convex mirror, the principal focus is a virtual focus, and is that point from which such rays appear to diverge after reflection from the mirror. This point will be found to be midway between the centre of curvature and the vertex of the mirror. There are many other foci possible,

that is, points through which reflected light rays are converged. However, there is only one principal focus as defined.

Focal Length, FV , is the distance from the principal focus to the vertex of the mirror.

The action of curved mirrors (Chap. 13, Exp. 6), may be demonstrated by means of the optical disc. Mount a concave mirror on the optical disc so that the 0° — 0° line becomes the principal axis of the mirror. Insert a metal shield with several parallel slits in the window of the opaque collar and shine light from a projection lantern through these slits onto the mirror (Fig. 9:12). You will note that the reflected rays converge. If the disc is rotated so that the incident rays are parallel to the principal axis it will be found that the reflected rays converge through a point. This point is the principal focus of the mirror. Similarly, if we insert a convex mirror in place of the concave one, and repeat the above, it will be found that the reflected rays diverge as though coming from a point behind the mirror. This virtual point locates the principal focus of the convex mirror.

II : 22 IMAGES IN A CONCAVE MIRROR

In experiment 7, chapter 13, we studied the characteristics and position of images formed by a concave mirror for different positions of the object. As the object was moved closer to the mirror, the image, which was real and

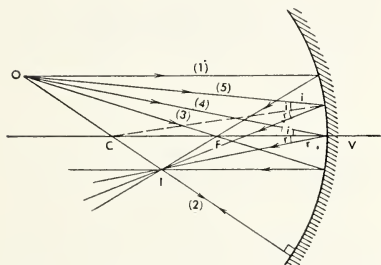


Fig. 9:13 Rays Used to Locate the Image, I , of an Object, O , in a Concave Mirror.

inverted, gradually grew larger in size and moved farther from the mirror. When the object was located inside the principal focus of the mirror, the image became virtual and erect and was located behind the mirror.

All of these results can be verified with fair accuracy by means of simple geometric diagrams. The principles used here are very similar to those used previously with plane mirrors. Each point on the object is sending out rays of light in straight lines in all directions. If we trace the paths of several of these rays from a point on the object, to the mirror, and then their reflected rays back from the mirror, we will find that they intersect. The point of intersection is the point on the image that corresponds to the original point on the object from whence the light rays came.

Suitable rays for this purpose, as illustrated in Fig. 9:13, are:

1. A ray from the object parallel to the principal axis, which will be reflected through the principal focus.
2. A ray from the object through the centre of curvature which will be reflected back along the same path, since the incident ray strikes the mirror at right angles.
3. A ray from the object through the principal focus, which will be reflected parallel to the principal axis.
4. A ray from the object to the vertex of the mirror, which will be reflected so that the angle of incidence equals the angle of reflection.
5. Any other ray from the object to the mirror will be reflected so that $\angle i = \angle r$.

In actual practice any two of these rays will suffice. The first two mentioned are the most easily drawn and hence are the most convenient to use.

In order to verify the observations obtained in our experiment, it is necessary to make accurate scale drawings.

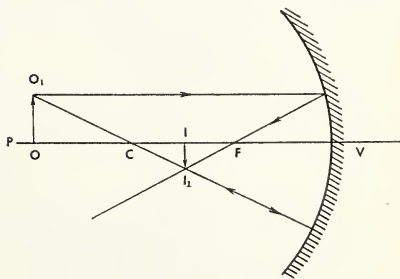


Fig. 9:14 To Locate the Image in a Concave Mirror of an Object Placed Beyond F .

For example, if the focal length of the concave mirror was 20 cm., the object 60 cm. from the mirror, and 12 cm. high, our construction would be as above (Fig. 9:14), using the scale 10 cm. = 1 cm.

Draw principal axis, PV . With centre C , and radius of curvature 4 cm. (twice focal length), draw an arc to represent the mirror. Locate the principal focus F , midway between C and V (2 cm. from mirror). Locate the object O , 6 cm. from the mirror. Draw the object (OO_1) 1.2 cm. high and perpendicular to the axis. From the tip of the object (O_1) draw the two rays and their reflected rays as outlined on previous page. These rays intersect at I_1 , and hence locate the position of the tip of the image. (Rays from other points on the object would produce corresponding image points. However, the one is sufficient.) Draw the image II_1 , perpendicular to PV . The distance of the image from the mirror and its size can be obtained by measuring accurately. Notice that when the object is beyond C , the image is between F and C , real, smaller than the object, and inverted. See how perfectly this diagram confirms your observations recorded in the table on page 140.

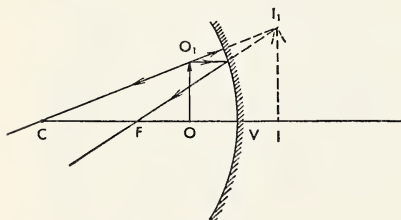


Fig. 9:15 To Locate the Image in a Concave Mirror of an Object Placed Between F and V .

The student should construct similar diagrams for other positions of the object, and verify the other observations made. The special case, where a virtual image is obtained, is slightly more difficult. Study the following diagram carefully, and note that the method is identical to that given previously (Fig.

9:15). However, this time the reflected rays diverge, and therefore appear to come from a point behind the mirror, thereby creating the virtual image.

II : 23 IMAGES IN A CONVEX MIRROR

One has often observed the images produced by the back of a spoon, the side of a tea-kettle or the shiny fender of a car. Such objects as these are all acting as convex mirrors. In experiment

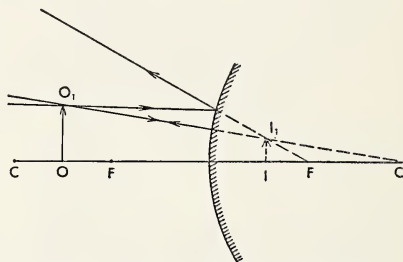


Fig. 9:16 To Locate the Image in a Convex Mirror.

8, chapter 13, we found that the images in a convex mirror were always behind the mirror, virtual, smaller than the object, and erect. The same method is used as with the concave mirror to verify this geometrically (Fig. 9:16).

II : 24 HOW THE EYE SEES THE IMAGE

As previously discussed in section II:19, the eye sees the image by means of rays which actually come from the object, but which appear to come from

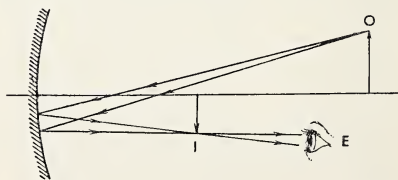


Fig. 9:17 How the Eye Sees a Real Image in a Concave Mirror.

the image. Fig. 9:17 and 9:18 show how this is accomplished. In each case the light rays start from the object, are reflected at the mirror, pass through a real image or appear to come from a

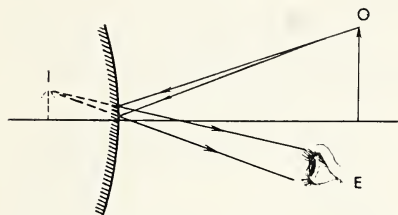


Fig. 9:18 How the Eye Sees a Virtual Image in a Convex Mirror.

virtual image, and enter the eye. In order to construct these diagrams just reverse the previous order. That is, join I to the outer edges of the pupil of the eye. This cone is projected back to the mirror or cuts the mirror. From there it is drawn back to the object.

II:25 THE MIRROR FORMULAE

In the previous sections we have been studying the images produced by curved mirrors. It is possible by means of two simple formulae to determine the location and characteristics of the image for various positions of the object. To do

so, a consistent convention regarding signs must be followed. Values for distances of objects and real images are always positive; those for virtual images are negative. Similarly, the focal length of a concave mirror (which has a real principal focus) is positive, that of a convex mirror (with a virtual principal focus) is negative. To state this concisely, the convention of signs is:

“real is positive, virtual is negative”

The two formulae, with worked examples to show how to use them, follow:

(a) Magnification Formula

$$\frac{\text{Height of Image}}{\text{Height of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

Note the similarity of this formula with that obtained for the pin-hole camera (Sec. II:4).

(b) Distance Formula

$$\begin{aligned} \frac{1}{\text{Distance of Object}} + \frac{1}{\text{Distance of Image}} &= \frac{1}{\text{Focal Length}} \\ \frac{1}{D_o} + \frac{1}{D_i} &= \frac{1}{f} \end{aligned}$$

Examples

1. An object 2 in. tall is placed 15 in. from a concave mirror whose focal length is 5 in. Find the position and size of the image.

$$\begin{aligned} H_o &= 2 \text{ in.} & \therefore \frac{1}{D_o} + \frac{1}{D_i} &= \frac{1}{f} \\ D_o &= 15 \text{ in.} & & \\ f &= 5 \text{ in.} & \therefore \frac{1}{15} + \frac{1}{D_i} &= \frac{1}{5} \\ D_i &= ? & \therefore \frac{1}{D_i} &= \frac{1}{5} - \frac{1}{15} = \frac{3-1}{15} \\ & & \therefore 2 D_i &= 15 \\ & & \therefore D_i &= 7.5 \\ & & \therefore \text{The image is located } 7.5 \text{ in. from the mirror.} & \end{aligned}$$

$$\begin{aligned}
 H_o &= 2 \text{ in.} & \therefore \frac{H_i}{H_o} &= \frac{D_i}{D_o} \\
 D_o &= 15 \text{ in.} & \therefore \frac{H_i}{2} &= \frac{7.5}{15} \\
 D_i &= 7.5 \text{ in.} & \therefore H_i &= 1 \\
 H_i &= ? & \therefore \text{The image is 1 in. tall.}
 \end{aligned}$$

Check these results by making an accurate scale construction to locate the image geometrically. Both position and size of image should agree closely with the above values obtained by calculation.

2. An object 5 cm. high is placed 30 cm. from a convex mirror whose focal length is 20 cm. Find the position, size, and nature of the image.

$$\begin{aligned}
 H_o &= 5 \text{ cm.} & \therefore \frac{1}{D_o} + \frac{1}{D_i} &= \frac{1}{f} \\
 D_o &= 30 \text{ cm.} & & \\
 f &= -20 \text{ cm.} & & \\
 D_i &= ? & \therefore \frac{1}{30} + \frac{1}{D_i} &= \frac{1}{-20} \\
 & & \therefore \frac{1}{D_i} &= -\frac{1}{20} - \frac{1}{30} \\
 & & &= \frac{-3-2}{60} \\
 & & \therefore -5 D_i &= 60 \\
 & & \therefore D_i &= -12 \text{ cm.}
 \end{aligned}$$

$\therefore$ Image is 12 cm. from mirror and is virtual (since sign is negative).

$$\begin{aligned}
 H_o &= 5 \text{ cm.} & \therefore \frac{H_i}{H_o} &= \frac{D_i}{D_o} \\
 D_o &= 30 \text{ cm.} & \therefore \frac{H_i}{5} &= \frac{12}{30} \\
 D_i &= 12 \text{ cm.} & \therefore H_i &= 2 \text{ cm.} \\
 H_i &= ? & \therefore \text{Image is 2 cm. high.}
 \end{aligned}$$

II : 26 APPLICATIONS OF MIRRORS

Reference has already been made in section II:18 to the uses of plane mirrors. Many of these uses, however, are more satisfactorily fulfilled by using curved mirrors. For example, a plane mirror is frequently used as a shaving mirror. However, a concave mirror so used produces an enlarged erect image when the face is held between the principal focus and the vertex of the mirror. The enlarged image is often a

distinct advantage. Similarly, a convex mirror is frequently used as a rear vision mirror instead of a plane mirror. The erect, smaller image produced gives a wider field of view with the same size mirror.

Spherical mirrors such as we have been describing have one serious defect, known as **spherical aberration**. In such mirrors, only those rays parallel to the principal axis and fairly near to it pass through the principal focus on being

reflected from the mirror. Rays farther from the principal axis are reflected through points some distance from the focus (Fig. 9:19). Conversely, if a source of light is placed at the principal focus, the reflected rays will not form a parallel beam, but the outer ones will be scattered and hence the light is weakened.

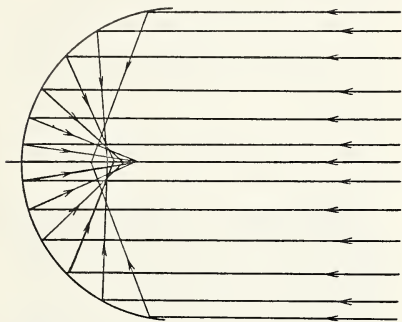


Fig. 9:19 Spherical Aberration in Curved Mirrors.

To overcome this defect, parabolic rather than spherical mirrors are used

(Fig. 9:20). A parabola is a section from a cone obtained by cutting the cone

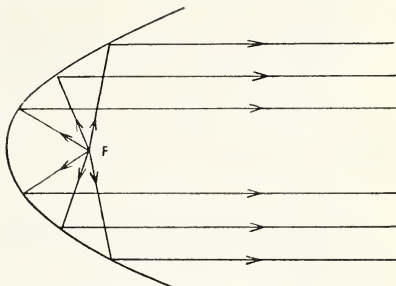


Fig. 9:20 A Parabolic Mirror Used to Prevent Spherical Aberration.

by a plane parallel to a line from the apex of the cone to any point on the circumference of the circular base. All rays which emanate from the principal focus of such a mirror, after reflection are parallel to the principal axis, no matter how great the aperture is. As a result parabolic mirrors are used as reflectors for searchlights, car headlights and in the reflecting telescope.

II : 27

QUESTIONS

A

- Define: angle of incidence, angle of reflection.
 - State the two laws of reflection and indicate how you could test them.
- Distinguish between diffuse and regular reflection.
 - How is undesirable glare decreased?
- State the rule for determining the position of an image in a plane mirror.
 - Describe the image.
 - Distinguish between real and virtual images.
- Show by a diagram how you can

locate the image of an inclined arrow in a plane mirror.

(b) Show how an eye sees the image.

- How many images will be observed in 2 mirrors inclined at 45° ?
 - Draw a diagram to locate these images.
- Define: principal axis, principal focus, focal length.
 - By means of accurate construction show how the principal focus of (i) a concave mirror, and (ii) a convex mirror may be located.
- Under what conditions does a concave mirror form (i) a real image, (ii) a virtual image?

- (b) Describe the size and location of all the real images produced by a concave mirror.
- (c) When a concave mirror is used in shaving, where is the person's face in relation to the principal focus of the mirror? What kind of image is seen?
8. An object is located just beyond the centre of curvature of a concave mirror.
- (a) By means of a diagram locate its image.
- (b) Show how the eye sees the image.
- (c) State the characteristics of the image.
9. (a) State uses of plane, concave and convex mirrors.
- (b) How does a searchlight produce a narrow beam of light?

B

1. A watch seen in a mirror seems to read (a) 2 o'clock, (b) 6.15 o'clock. What does it actually read? Explain.
2. Support a mirror vertically on a desk and stand a book in front of it to serve as a screen. Draw a triangle on a piece of paper and lay it flat between the book and the mirror. Watching the image in the mirror, but not the triangle itself, try to retrace the triangle. Why do you have difficulty?
3. What changes would you observe in your image as you walked toward (a) a plane mirror, (b) a concave mirror, (c) a convex mirror?
4. An object 15 cm. high is located (i) 75 cm. (ii) 60 cm. (iii) 45 cm. (iv) 30 cm. (v) 20 cm. from a concave mirror whose focal length is 30 cm.
- (a) By means of accurate scale diagrams locate the position of the image for each position of the object.
- (b) State the characteristics of each image.
5. By means of an accurate scale diagram locate the image produced by a convex mirror, whose focal length is 15 in., of an object 6 in. high and 2 ft. distant. State the characteristics of the image.
6. An object is 4 in. tall and its image is 6 in. tall when the object is placed 2 ft. from the mirror. How far is the image from the mirror?
7. A 6 in. pencil is 1 ft. in front of a curved mirror. Find the length of the image if it is 8 in. from the mirror.
8. How tall is an object if it produces an image 3 in. tall located 7 in. behind a convex mirror when the object is located 10 ft. in front of the mirror?
9. An object 4 in. in front of a concave mirror produces an image 12 in. behind the mirror. Find the focal length of the mirror.
10. An object is 18 cm. in front of a concave mirror which has a focal length of 12 cm. How far is the image from the mirror?
11. An object 9 in. from a convex mirror produces an image 3 in. behind the mirror. Find the focal length of the mirror.
12. An object is 15 cm. from a convex mirror of focal length 20 cm. Calculate the image distance.
13. The focal length of a concave mirror is 12 in. How tall is the image of a 5 in. candle standing 15 in. from the mirror?
14. Repeat question 13 using a convex instead of a concave mirror.

CHAPTER 10

REFRACTION OF LIGHT— LENSES

II : 28 MEANING OF REFRACTION

Water frequently appears to be much shallower than it actually is. An oar or stick when only partly submerged appears to be bent upwards at the surface of the water (Fig. 10:1). These phenomena, and many others similar to them, are due to the bending of light rays as they pass obliquely from one medium into another of different optical

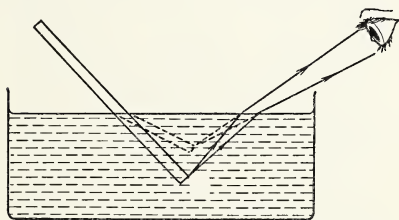


Fig. 10:1 Partly Immersed Stick Appears Bent.

density (Sec. II:29). Such bending of the light rays is called **refraction**.

Refraction of light as it passes from air into water, or from water into air, can be illustrated easily. Fill a tank with water containing a small amount of fluorescein, or a little sodium thiosul-

phate (hypo) and a few drops of hydrochloric acid. These materials will render the water slightly turbid and make

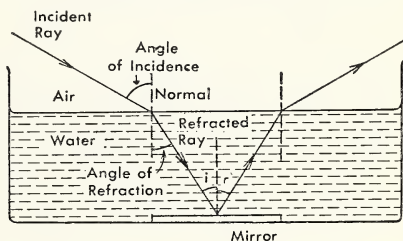


Fig. 10:2 Refraction of Light on Passing from Air to Water or from Water to Air.

visible a light beam projected through it. Shine a beam obliquely upon the surface of the water (Fig. 10:2). Part of this beam will be reflected at the surface of the water, and part will be refracted as it enters the water. If a normal (perpendicular) is placed at the point of incidence, it will be observed that the light beam is bent toward the normal. Similarly, if we shine the beam of light obliquely up through the water and into the air, it will be observed to bend away from the normal. Both effects can be shown simultaneously by placing a plane mirror on the bottom of the tank (Fig. 10:2). Note that no refraction occurs if the light enters or leaves the water at right angles to the surface.

We may also show that a beam of light is refracted on passing obliquely

from air into glass, or from glass into air. Place a semicircular block of glass on the optical disc, so that its flat edge is bisected at right angles by the $O^\circ-O^\circ$ axis of the optical disc. Shine a ray of light so that it strikes the surface at this central point where the axis crosses it. The axis thus is made the normal to the refracting surface. The light will

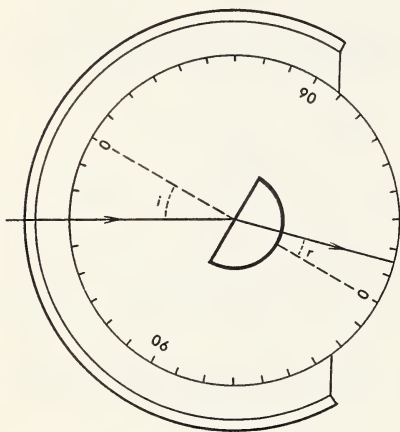


Fig. 10:3 Refraction of Light on Passing from Air to Glass.

be refracted as shown in Fig. 10:3. Why is the light not refracted on leaving, or on entering the circular surface of the glass?

From the preceding observations we may summarize the behaviour of light rays in passing from one medium into another of different optical density, as follows:

1. When a ray of light passes obliquely from one medium into another of greater optical density, it is refracted toward the normal.
2. When a ray of light passes obliquely from one medium into another of less optical density, it is refracted away from the normal.

It follows from the above that when a ray of light enters a new medium at right angles to the surface, no refraction occurs.

II : 29 EXPLANATION OF REFRACTION

We may ask what causes refraction of light. The following illustration should help us to understand it. Suppose the brakes of an automobile are improperly adjusted, those on the right wheels holding better than those on the left. When the brakes are applied, the car will swerve to the right, that is, to the side that is slowed up most. Similarly, the bending of the light beam, or refraction, is caused by the change in the velocity of light as it passes from one medium into another of different optical density. The greater the optical density of a substance the more slowly light will travel through it.

According to the wave theory, light travels out from the source as spherical waves. When a wave-front enters an optically denser medium obliquely (Fig. 10:4), that part of it that enters the new medium first will be slowed, while the rest of it continues to advance at the same speed as before. Consequently, the wave-front swerves toward the normal as it enters the denser medium. Conversely, the wave-front would swerve away from the normal as it speeds up on passing into an optically less dense medium. No bending occurs if the light enters the new medium at right angles to the surface, for the entire wave-front would be slowed down or speeded up at the same instant.

II : 30 INDEX OF REFRACTION

From Fig. 10:4 it is evident that the light is travelling the distance PR in one medium (air), while it travels the distance OQ in the other medium. Hence these distances must be proportional to

the velocities of the light in the two media. Also, it should be evident that the amount of refraction is governed by these

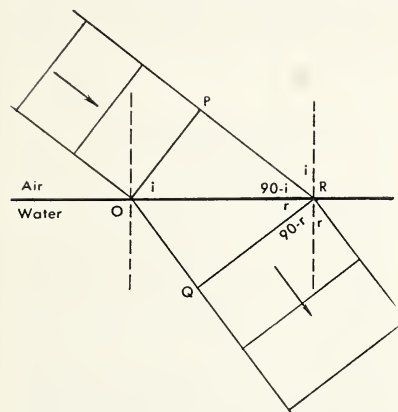


Fig. 10:4 Refraction of Wave Front on Entering an Optically Denser Medium.

relative distances or these relative velocities, and would be constant for any two given media. This ratio is called the **index of refraction**, and may be defined as follows:

$$\begin{aligned} \text{Index of Refraction of a medium } (\mu) &= \frac{\text{Velocity of light in air}}{\text{Velocity of light in the medium}} \\ &= \frac{V(\text{air})}{V(\text{medium})} \end{aligned}$$

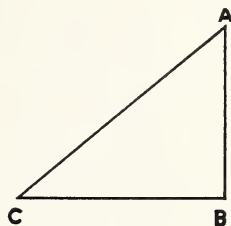
In experiment 9, chapter 13, by means of a simple geometric construction it is shown that

Index of Refraction

$$= \frac{\text{Sine of angle of incidence}^*}{\text{Sine of angle of refraction}}$$

The sine of an angle (abbreviated $\sin \angle$) is a property of an angle found useful in calculations in mathematics and science.

In the study of refraction only acute angles are involved. When the angle is contained in a right-angled triangle, its sine is a constant quantity found by dividing the length of the side opposite



the angle by the length of the hypotenuse. For example, in $\triangle ABC$,

$$\sin \angle ACB = \frac{AB}{AC} \text{ and}$$

$$\sin \angle CAB = \frac{BC}{AC}$$

*To prove that:

$$\begin{aligned} \text{Index of Refraction } (\mu) &= \frac{\sin \angle i}{\sin \angle r} \\ \mu &= \frac{V(\text{air})}{V(\text{medium})} = \frac{PR}{OQ} \\ \frac{\sin \angle i}{\sin \angle r} &= \frac{PR/OR}{OQ/OR} = \frac{PR}{OQ} \\ \therefore \mu &= \frac{\sin \angle i}{\sin \angle r} \end{aligned}$$

The index of refraction is an important physical property of a transparent medium. An instrument, called a refractometer is used to measure its value quickly and accurately. This enables scientists to identify substances and to check their purity. If the index of refraction of a substance is known the velocity of light may be determined for that substance. A substance with a large index of refraction is said to have a

high optical density, because it permits light to travel through it at a relatively slow velocity. Such substances refract light to a greater extent than do those with a smaller index of refraction. The brilliance of diamonds, and other precious stones is largely due to this fact (Sec. II:33). The index of refraction of a substance varies with the colour of the light that passes through it. The rainbow and the beautiful colours obtained when light is refracted through cut glass and precious stones are due to this (Sec. II:44). Temperature, too, has an effect on the index of refraction because it alters the optical density of a substance. The waviness observed when light passes through air rising above a hot object is caused by the differing refractive indices of various layers of hot and cold air.

THE INDEX OF REFRACTION OF SOME COMMON SUBSTANCES

Water	1.3	Quartz	1.5
Crown Glass	1.5	Zircon	1.9
Flint Glass	1.7	Diamond	2.4

II : 31 REFRACTION THROUGH A GLASS PLATE

When a ray of light passes obliquely through a glass plate with parallel sides (Chap. 13, Exp. 10), it is refracted both on entering and on leaving the glass. On entering, the light is slowed down and

is, therefore, refracted toward the normal. On emerging, the light speeds up again, and hence is refracted away from the normal. Since this second effect exactly counteracts the first (i.e., the speeding up exactly compensates for the

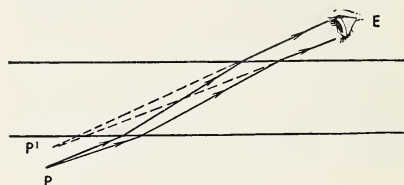


Fig. 10:6 Why an Object Appears Closer When Viewed Through a Glass Plate.

original slowing down), the emergent ray will be parallel to the incident ray but laterally displaced (Fig. 10:5). The amount of this lateral displacement depends on the refractive index of the glass, on the angle of incidence, and on the thickness of the glass. On looking at an object through such a plate, it will be slightly displaced in position and will appear nearer to the eye than it is in fact (Fig. 10:6). The same thing occurs in water and this accounts for the difficulty in locating the exact position of an immersed object (Chap. 13, Exp. 11).

II : 32 REFRACTION THROUGH PRISMS

A **prism** consists of a wedge-shaped portion of a refracting substance, bounded by two plane surfaces inclined at an angle to each other, this angle being called the refracting angle. When a ray of light enters such a prism it is slowed down, and therefore refracted toward the normal. On leaving, it speeds up, and therefore bends away from the normal. This can be shown by mounting a 60° prism on an optical disc and shining a ray of monochromatic light, e.g., red, through it. From Fig. 10:7 it is seen

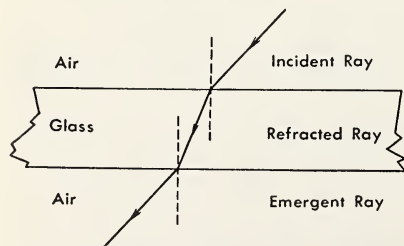


Fig. 10:5 Refraction Through a Glass Plate with Parallel Sides.

that both these refractions are toward the thick base of the prism. Hence the light is bent, or deviated, quite consid-

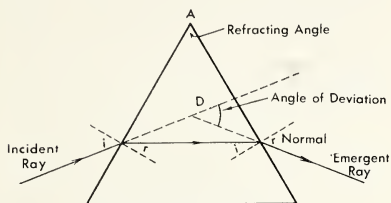


Fig. 10:7 Deviation Through a Glass Prism.

erably from its original path. The angle of deviation, D , is obtained by extending the incident and emergent rays to meet (Chap. 13, Exp. 12).

The amount of deviation produced by a prism depends upon a number of factors. First, the material comprising the prism—the greater its index of refraction, the greater will be the deviation produced. Secondly, the shape of the prism—the greater its refracting angle, the greater will be the angle of deviation. Thirdly, the angle of incidence at which the light meets the prism. This can be shown by rotating the optical disc and observing the amount of deviation for various angles of incidence. Minimum deviation is obtained from an equilateral

prism when the refracted ray passes through the prism parallel to the base. Finally, the amount of deviation depends upon the colour, or the wavelength, of the light used, which is why monochromatic light was used in these experiments. This latter factor gives prisms one of their large areas of usefulness. More discussion on this follows in the chapter on colour, page 110.

II:33 TOTAL REFLECTION

It is more usual to consider light passing from air into an optically denser medium; however, when it goes from the optically denser medium into air, or a less dense medium such as from water or glass into air, a peculiar phenomenon occurs. As the light speeds up on entering the air obliquely it bends away from the normal. As the angle of incidence in the denser medium increases, we finally come to a position when the refracted ray just grazes the surface, that is, the angle of refraction equals 90° . This angle of incidence is called the **critical angle**. When the incident angle exceeds the critical angle the light is completely reflected, a phenomenon known as **total reflection** (Fig. 10:8). Using the semicircular block of glass on the optical disc as in section II:28, shine a ray of light through it. Rotate the disc to increase the angle of

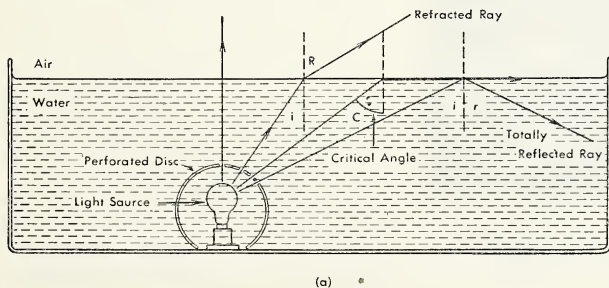


Fig. 10:8 Total Reflection of Light (a) On Passing from Water to Air. (b) On Passing from Glass to Air.

incidence and note the size when total reflection first occurs. This angle, the critical angle for glass, is about 42° .

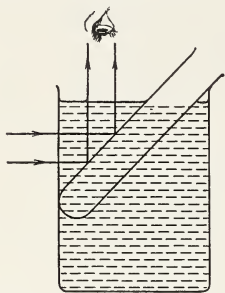


Fig. 10:9 An Illustration of Total Reflection.

An example of total reflection is seen when an empty test-tube is placed in a



Canadian Industries Ltd.

An Interesting Example of Light Being "Bent" in a "Perspex" Rod.

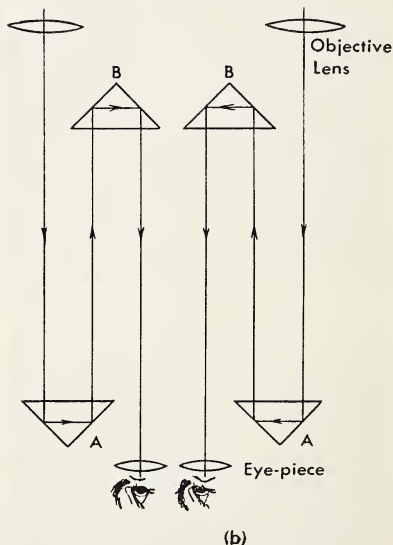
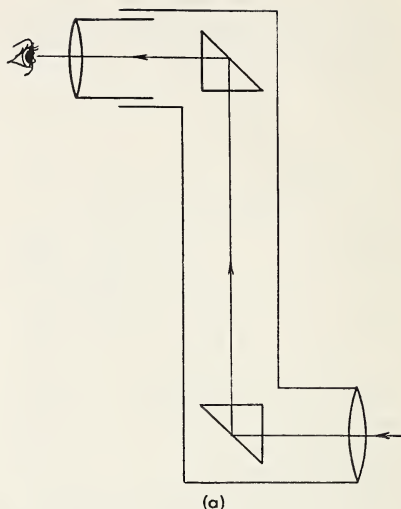


Fig. 10:10 Applications of Total Reflection Prisms (a) A Simple Periscope. (b) Field Glasses.

beaker of water (Fig. 10:9). On looking down into the water the sides of

the test-tube appear silvery. This is due to the light striking the surface of the tube at an angle greater than the critical angle for glass. This light is totally reflected to the eye as shown. Similarly a sooted ball appears silvery on being lowered into a beaker of water. A layer of air entrapped by the coating of soot produces a water-air boundary at which reflection occurs.

Total reflection is a very useful phenomenon. Total reflection prisms are usually right-angled prisms with well-polished faces. Light strikes one face at an angle of incidence of 45° , which is greater than the critical angle for glass (p. 98), and hence total reflection occurs. Such prisms are used in periscopes (Fig. 10:10a), range finders, field-glasses (Fig. 10:10b), and reflecting telescopes. They are much more efficient reflectors than mirrors, since mirrors reflect only about seventy per cent of the light they receive, whereas prisms reflect a much greater proportion. In addition, prisms are more robust, there is no silvering to tarnish and they give rise to a single well-defined image.

The brilliancy of diamonds, brilliants, and cut-glass dishes is due to total reflection. The greater the index of refraction of a substance the smaller is its critical angle. Diamonds have a large index of refraction (Sec. II:30) and consequently have a small critical angle. The surfaces of the diamonds meet each other at such angles that much of the light entering a diamond is totally reflected a number of times internally, before eventually being refracted out. This lights up many surfaces, and gives the diamond its sparkle. Brilliants, and cut-glass articles are often made of leaded glass. The addition of lead increases the index of refraction, and consequently the cut faces are able to cause much total reflection.

II : 34 ATMOSPHERIC REFRACTION

Light travels faster in a vacuum than in air. Therefore, light reaching us from the sun and stars will slow up and be refracted as it enters the atmosphere of the earth. Since the atmosphere gradually becomes denser as the altitude decreases, the light will be refracted more and more as it passes through successive layers of denser air nearer the surface. Consequently, when light comes to us obliquely from the sun and stars these

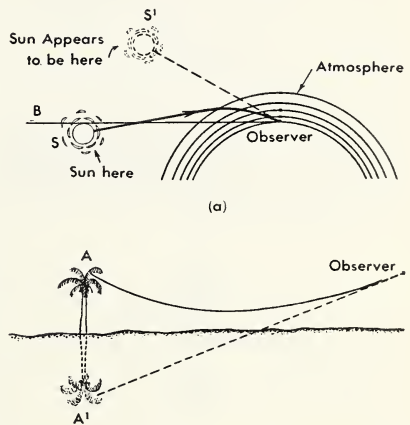


Fig. 10:11 Atmospheric Refraction
(a) The Sun Low on the Horizon.
(b) A Mirage.

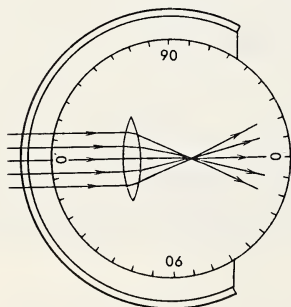
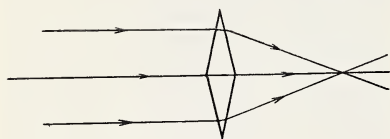
bright objects appear higher than they really are (Fig. 10:11a). This effect is most pronounced at low altitudes because of the larger angles of incidence, and the increased distances to be travelled through the successive layers of air. As a result the sun appears to set several minutes after it has actually passed below the horizon. The enlarged and sometimes elliptical appearance of the sun and moon when near the horizon is due to the fact that rays from the

lower edge are refracted more than those from the upper edge.

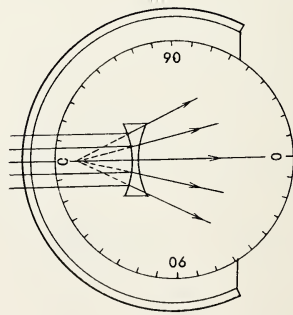
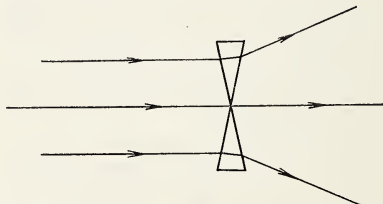
A mirage is a well-known optical illusion caused by refraction and sometimes total reflection of light as it passes through layers of atmosphere of varying density (Fig. 10:11b). Objects in the distance may be raised above or depressed below their normal position and may be distorted into irregular fantastic shapes. The most commonly observed mirage is that of an apparent layer of water over a hot level sandy surface, or paved roadway. The mirage in these cases is really an image of the sky, produced by total reflection from layers of air near the ground.

II : 35 LENSES

A lens is a piece of transparent refracting medium, usually glass, bounded by two spherical surfaces, or by a plane and a spherical surface.



(a)



(b)

Fig. 10:13 Comparison of Lenses and Prisms. (a) Action of a Converging Lens. (b) Action of a Diverging Lens.

There are two main types:

- (a) **Converging or Convex Lenses** are thicker at the centre than at the outer edge. Such lenses always refract rays of light so as to converge them. They therefore collect light.

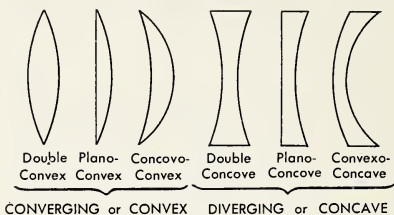


Fig. 10:12 Kinds of Lenses.

- (b) **Diverging or Concave Lenses** are thinner at the centre than at the outer edge. These lenses cause light rays to diverge. They therefore scatter light.

These two types of lenses may be of varying shapes as shown in Fig. 10:12. Each shape is devised for a specific purpose.

The action of a lens is similar to that of two prisms base to base (Fig. 10:13). As discussed in section II:32, the light is bent toward the base of the prism both on entering and leaving the prism. Similarly, the light is bent toward the thicker part of the lens both on entering and leaving it. These examples explain the converging action of a convex lens, and the diverging action of a concave lens.

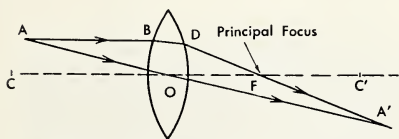


Fig. 10:14 Terms Pertaining to Lenses.

The study of lenses makes use of a new vocabulary. The terms used are explained below (Fig. 10:14):

Centre of Curvature C , C' : In most lenses there are two centres of curvature. They are the centres of the spherical surfaces that bound the lens.

Principal Axis of a lens is the line passing through the centres of curvature of the two faces, or, in the case of a lens which has one face plane, it is the line passing through the centre of curvature of the curved face and which is normal to the plane face.

Optical Centre O , is the point on the principal axis midway between the two surfaces of the lens. All distances along the principal axis are measured from this point.

Principal Focus F , of a convex lens is that point on the principal axis to which a beam of light which is parallel to the principal axis converges

after refraction through the lens. (In a concave lens, the principal focus is a virtual point, and is that point on the principal axis from which a beam of light, which is parallel to the principal axis, appears to diverge on being refracted through the lens.)

Focal Plane is a surface that passes through the principal focus perpendicular to the principal axis of the lens.

Focal Length is the distance of the principal focus from the optical centre of the lens.

Note 1: In Fig. 10:15 (see below) a line has been drawn through the optical centre of the lens perpendicular to the principal axis. For simplicity, we may represent the entire refraction of light as occurring at this line. Actually, of course, a light ray will be refracted both

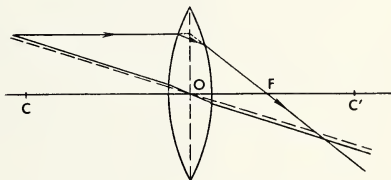


Fig. 10:15 Represented and Actual Paths of Light Through a Lens.

on entering and on leaving the lens. This actual path of the light through the lens is shown by drawing a line between the point where the incident ray enters the lens, and the point where the refracted ray leaves the lens.

Note 2: A ray through the optical centre of a lens may be considered as passing straight through the lens. This is because the surfaces of the lens through which the light is travelling are almost parallel. Therefore, the light will be refracted on entering and on leaving

in such a way that the emergent ray will be parallel to, but laterally displaced from, the incident ray (Sec. II:31). We shall consider all our lenses to be very thin, so that the amount of lateral displacement is negligible.

II:36 FOCAL LENGTH OF LENSES

To determine the focal length of a lens the position of the principal focus

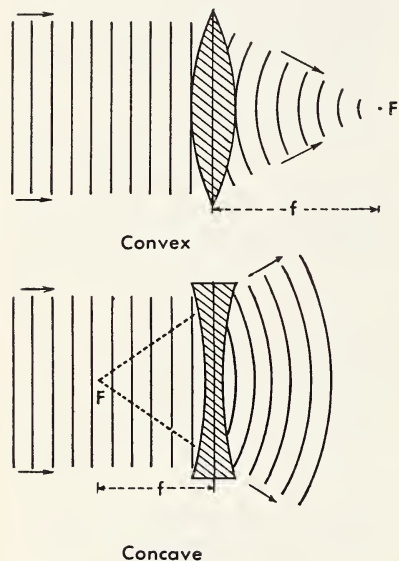


Fig. 10:16 Principal Focus of a Convex Lens and a Concave Lens

must first be determined and then its distance from the optical centre of the lens measured (Chap. 13, Exp. 13). This may be demonstrated by placing a convex lens on an optical disc. Shine a number of rays, parallel to the principal axis, through the disc and note the point through which they converge. This point is the principal focus (Fig. 10:16). The focal length depends upon the index of refraction of the lens and its thickness.

Increasing either or both of these increases the amount of bending of the light and so shortens the focal length. The powers of lenses used in most optical instruments are usually expressed in terms of their focal lengths.

In optometry it is more usual to deal with the power of a lens rather than its focal length. The unit of power is the **dioptré**, which is the power of a converging lens of focal length one metre (100 centimetres). The shorter the focal length, the greater the power of the lens, and accordingly the power can be related to the focal length by the formula:

$$P \text{ (dioptrés)} = \frac{100}{f \text{ (cm.)}}$$

According to our convention of signs (Sec. II:25, and II:39), a convex lens with a real principal focus has a positive focal length and a + power; a concave lens with a virtual principal focus has a negative focal length and a - power.

If a lens is used in a different medium, its focal length and therefore its power will change. This can be shown by placing a lens in a tank of turbid water (Fig. 10:17). Shine a parallel beam of

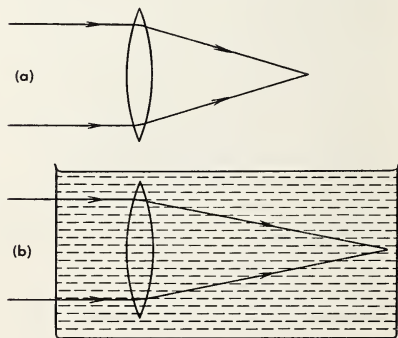


Fig. 10:17 Comparison of Focal Lengths of Lens (a) In Air (b) Immersed in Water.

light through the water and the lens, and compare the focal length in water with that previously obtained in air. It will be found to be longer. This is to be expected as there is a smaller decrease in velocity of the light going from water to glass than when going from air to glass. Consequently there is less bending of the light, and therefore a longer focal length. A convex air lens in water would function as a diverging lens. Explain why. It can be constructed by cementing watch glasses together using a waterproof cement.

Care should be observed in the use and location of spherical transparent objects.

For example, a glass globe of water in sunlight could focus the sun's rays. If flammable material should be located at the principal focus of this lens a fire could easily result. Use is made of this very fact in some types of sunlight recorders used by weather bureaus.

A sunlight recorder is a device used to determine the number of hours of bright sunshine. In Ontario, the meteorological department uses the Campbell-Stokes Sunshine Recorder (Fig. 10:18). It consists essentially of two parts:

- (1) A glass sphere which brings the sun's rays to a focus.
- (2) An approximately spherical metal

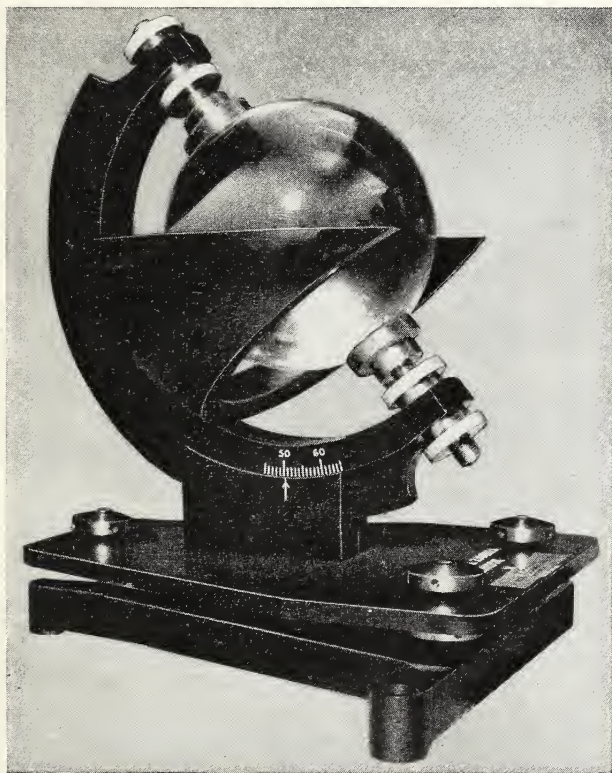


Fig. 10:18

A Sunlight Recorder.

bowl carries cards which form a belt on which the sun burns a record.

Real care must be observed in setting up the recorder. There must be no obstructions that would shield the recorder from the sun's rays. It must be placed on a rigid table, and made perfectly level. Instructions are always provided for adjusting for latitude, and for adjusting for the time meridian. The glass ball must be kept perfectly clean at all times.

II : 37 IMAGES IN CONVEX LENSES

Previously we saw how images were formed in concave mirrors (Sec. II: 22). Convex lenses form a very similar series of images by refracting the light that passes through them. In experiment 14, chapter 13 the method of studying the characteristics and position of the images formed is given. It will be found that as the object approaches the lens up to the focal plane the image formed on the opposite side of the lens is real, inverted, and gradually becomes larger in size as it moves farther from the lens. When the object is located inside the focal plane, the image becomes virtual, erect, and is located on the same side of the lens as the object.

As in mirrors, so in lenses, it is possible to verify these results by means of simple geometric diagrams. To do so it is necessary to draw two rays from any point on the object, and determine through what point they are focused by the lens (Fig. 10:19). The two most suitable rays are:

- (1) A ray from the tip of the object parallel to the principal axis. This ray on passing through the lens is refracted through the principal focus.
- (2) A ray from the tip of the object through the optical centre of the

lens. This ray may be considered as passing straight through the lens (Sec. II:35).

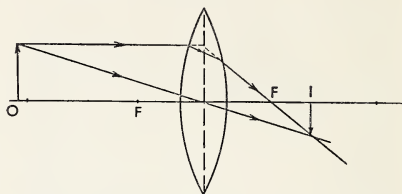


Fig. 10:19 To Locate a Real Image in a Convex Lens.

The point where these two refracted rays cross locates the tip of the image. A similar construction for other points on the object will locate the corresponding points on the image.

Fig. 10:20 shows how to locate the virtual image obtained when the object is inside the focal plane of the lens.

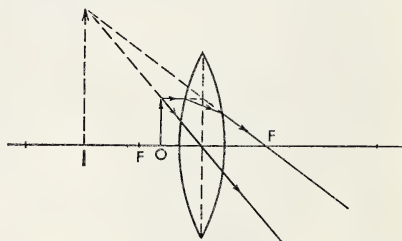


Fig. 10:20 To Locate a Virtual Image in a Convex Lens.

The construction is identical to that just described. Because the refracted rays diverge from each other, it is necessary to produce them back to where they appear to meet.

II : 38 IMAGES IN CONCAVE LENSES

By referring to experiment 15 chapter 13 it will be observed that concave lenses can form virtual images only. These are

always erect, smaller than the object, and located at less than the focal distance from the lens (Fig. 10:21). A close similarity will be noted between the images formed by concave lenses and those formed by convex mirrors (Sec. II:23).

Fig. 10:22 shows how the eye sees the image produced by a lens.

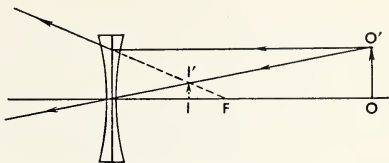


Fig. 10:21 To Locate the Image of an Object in a Concave Lens.

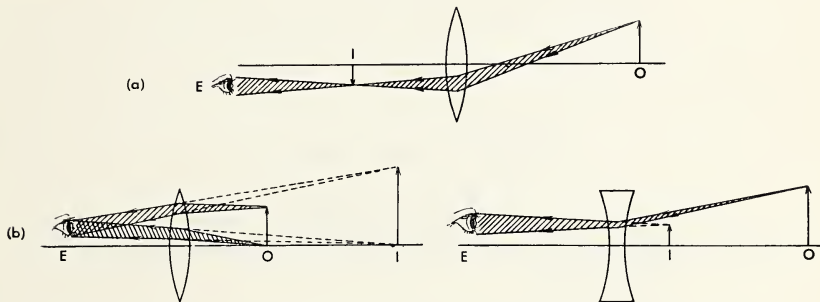


Fig. 10:22 How the Eye Sees the Image Produced by a Lens. (a) Real Images. (b) Virtual Images.

II : 39 THE LENS FORMULAE

The formulae we obtained for curved mirrors (Sec. II:25) also apply to lenses, that is,

(a) Magnification Formula

$$\frac{\text{Height of Image}}{\text{Height of Object}} = \frac{\text{Distance of Image}}{\text{Distance of Object}}$$

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

(b) Distance Formula

$$\frac{1}{\text{Distance of Object}} + \frac{1}{\text{Distance of Image}} = \frac{1}{\text{Focal Length}}$$

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

The same convention of signs must be followed, namely: real is positive, virtual is negative.

Examples

1. An object 5 cm. tall is placed 30 cm. from a convex lens whose focal length is 10 cm.

- (a) By means of an accurate scale diagram locate the image, and state its characteristics.

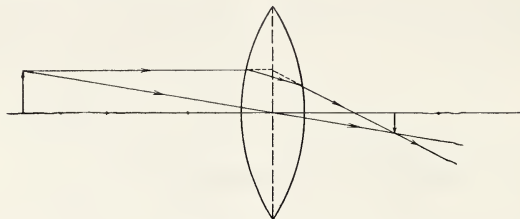


Fig. 10:23 Scale 5 cm. = $\frac{1}{4}$ in.

- (b) By using the lens formulae, determine the position of the image, and its size. How could you tell from your answer whether it is real or virtual?

$$D_o = 30 \text{ cm.}$$

$$f = 10 \text{ cm.}$$

$$D_i = ?$$

$$\therefore \frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

$$\therefore \frac{1}{30} + \frac{1}{D_i} = \frac{1}{10}$$

$$\therefore \frac{1}{D_i} = \frac{1}{10} - \frac{1}{30}$$

$$= \frac{3 - 1}{30}$$

$$\therefore D_i = 15$$

$\therefore$ Image distance is 15 cm.

Note: Since the image distance is + 15 cm., therefore the image is real.

$$D_o = 30 \text{ cm.}$$

$$D_i = 15 \text{ cm.}$$

$$H_o = 5 \text{ cm.}$$

$$H_i = ?$$

$$\therefore \frac{H_i}{H_o} = \frac{D_i}{D_o}$$

$$\therefore \frac{H_i}{5} = \frac{15}{30}$$

$$\therefore H_i = 2.5$$

$\therefore$ Height of image is 2.5 cm.

2. A concave lens has a focal length of 4 in. An object 1 in. high is 12 in. from the lens.

(a) Determine the position and size of the image.

(b) Verify your answer by making an accurate scale diagram.

$$\begin{aligned}
 f &= -4 \text{ in.} \quad (\text{— since } f \text{ is virtual}) \\
 D_o &= 12 \text{ in.} \\
 H_o &= 1 \text{ in.}
 \end{aligned}
 \qquad
 \begin{aligned}
 \therefore \frac{1}{D_o} + \frac{1}{D_i} &= \frac{1}{f} \\
 \therefore \frac{1}{12} + \frac{1}{D_i} &= -\frac{1}{4} \\
 \therefore \frac{1}{D_i} &= -\frac{1}{4} - \frac{1}{12} \\
 &= \frac{-3-1}{12} \\
 \therefore D_i &= -3
 \end{aligned}$$

$\therefore$ Image distance is 3 in.

Note: Since the image distance is negative, therefore, the image is virtual.

$$\begin{aligned}
 H_i &= ? \\
 H_o &= 1 \text{ in.} \\
 D_i &= 3 \text{ in.} \\
 D_o &= 12 \text{ in.}
 \end{aligned}
 \qquad
 \begin{aligned}
 \therefore \frac{H_i}{H_o} &= \frac{D_i}{D_o} \\
 \therefore \frac{H_i}{1} &= \frac{3}{12} \\
 \therefore H_i &= .25
 \end{aligned}$$

$\therefore$ Height of image is .25 in.

II:40 APPLICATIONS OF LENSES

As lenses are an essential part of almost every optical instrument, a discussion of their major applications is reserved until chapter 12 where several optical instruments are described. However, to relate specifically to the facts learned in the preceding sections we will mention a few simple uses here. The camera (Sec. II:51), the eye (Sec. II:52), the telescope (Sec. II:55) and the projection lantern (Sec. II:56) all contain a convex lens as an essential part of their construction. All these in-

struments produce real, inverted images because the object viewed in each case is beyond the principal focus of the lens. In the magnifying glass (Sec. II:53) and microscope (Sec. II:54) an enlarged, erect, virtual image is obtained because the object is inside the principal focus of the convex lens. Concave lenses are used along with convex lenses in many optical instruments to overcome certain defects, e.g., chromatic aberration (Sec. II:49), that would be apparent if the convex lens were used alone.

II : 41

QUESTIONS

A

1. (a) Define refraction of light.
(b) Describe and explain the refraction of light as it passes obliquely from one medium into another of different optical density.
2. (a) Define index of refraction.
(b) Draw a diagram showing how you can see a coin lying on the bottom of a dish filled with water, though the coin would be hidden if the dish contained no water.
(c) What is the velocity of light in quartz? (See table p. 96 for index of refraction of quartz).
(d) The velocity of light in a diamond is 75,300 miles per second. What is its index of refraction?
3. (a) How do you account for the shimmering effect seen in the air above a hot radiator?
(b) How does the same principle account for the twinkling of the stars?
4. Place a thick glass plate on a line drawn on a piece of paper. View the line obliquely. Describe and explain what is observed.
5. (a) With the aid of a diagram explain why an oar appears bent when partly immersed in water and viewed obliquely.
(b) Is the index of refraction greater for glass in which the velocity of light is 124,000 miles per second, or for water, in which the velocity is 140,000 miles per second? Why?
6. (a) Define angle of deviation.
(b) State four factors that govern the amount of deviation produced by a prism.
(c) Is the index of refraction of glass constant for all colours of light? Explain your answer.
7. (a) Define critical angle. Illustrate your definition with a labelled diagram.
(b) Would the critical angle be greater for water (index of refraction 1.33) or for glass (index of refraction 1.5)? Why?
8. (a) Draw a diagram to show how a right-angled prism may be used to secure (i) one total internal reflection, (ii) two total internal reflections.
(b) Explain why total reflection occurs in these two cases.
(c) Why are total-reflection prisms preferable to mirrors in many optical instruments?
9. (a) Compare the action of lenses to that of two prisms.
(b) Define principal focus of a lens.
(c) How can you determine experimentally the focal length of a lens?
(d) Calculate the power of a lens whose focal length is 0.15 metres.
10. (a) What is the purpose of a sunlight recorder?
(b) What approximate position relative to the glass sphere should the recording-belt occupy in the sunlight recorder?
11. (a) Distinguish between convex and concave lenses.
(b) Summarize the types of images possible with both types of lenses and the conditions under which each is obtained.
12. An object is located at a point more than twice the focal length from a convex lens.
(a) By means of a diagram locate its image.
(b) State the characteristics of the image.
13. (a) What do we mean by the magnification produced by a lens?

(b) How does the magnification depend on image distance and object distance?

B

1. What is the index of refraction of a liquid in which the speed of light is 155,000 miles per second?

2. The index of refraction of diamond is 2.47; that of window glass is 1.51. How much faster does light travel in the glass than in diamond?

3. Light strikes the surface of glass making an angle of incidence of (a) 60° , (b) 45° , (c) 30° . The index of refraction of glass is 1.5. By means of accurate geometric diagrams draw the refracted ray for each case. Using a protractor, measure the angles of refraction.

4. By means of an accurate construction determine the size of the angle of incidence when the angle of deviation is a minimum in an equilateral crown-glass prism. Measure the angle of deviation.

5. In which material does light travel faster, one with a critical angle of 25° or one with a critical angle of 30° ? Explain, using appropriate diagrams.

6. An object 15 cm. high is located (i) 75 cm. (ii) 60 cm. (iii) 45 cm. (iv) 30 cm. (v) 20 cm. from a convex lens whose focal length is 30 cm.

(a) By means of accurate scale diagrams locate the position of the image for each position of the object.

(b) State the characteristics of each image.

7. By means of an accurate scale diagram locate the image produced by a concave lens whose focal length is 15 in. of an object 6 in. high and 2 ft. distant. State the characteristics of the image.

8. A camera forms an image 8 cm. from the lens. If the object is 400 cm. away and 250 cm. tall, what is the height of the image?

9. The image of a tree in a miniature camera is 50 mm. from the lens and 30 mm. high. The tree is 15 metres away. How tall is the tree?

10. The image of an object 3 in. from a lens is formed 20 ft. from the lens. How many times is it magnified?

11. The image of an object 24 ft. from a lens is focused clearly on a screen 3 ft. from the lens. What is the focal length of the lens?

12. A convex lens forms a virtual image at a point 12 cm. from the lens. The object distance is 8 cm. Find the focal length of the lens.

13. A tree 100 ft. from a camera lens has its image very close to the principal focus of the lens. If the tree is 66 ft. tall and the image is 4 in. tall, what is the focal length of the lens?

14. A candle is 12 cm. from a convex lens of focal length 8 cm. What is the distance from the lens to the image of the candle?

15. A student uses a convex lens to look at an object held 4 cm. from the lens. If the focal length of the lens is 5 cm., how far is the image from the lens? What kind of image is it?

16. The image in a camera is 10 cm. high and 14 cm. from the lens. If the object is 100 cm. tall, what is the focal length of the lens?

17. A jeweller uses a converging lens of focal length 1 in. to examine a diamond. The virtual image is 10 in. from the lens. Find (a) the object distance, (b) the magnification.

18. When photographing a scene at a distance of 6 ft. from the lens, you find that the distance between the lens and the film is 6 in.

(a) What is the focal length of the lens?

(b) What is the actual size of a portion of a scene which occupies a space 3 in. $\times$ 5 in. on the film?

11 : 42 INTRODUCTION TO COLOUR

Imagine how drab and uninteresting the world would be if there were no colour. Think of the pleasure and stimulation we receive from the colours of nature—the blue sky, the green grass, the beautiful flowers, the gorgeous hues of the sunrise and sunset. The use of colour in photography, in movies, and in book illustrations has added tremendously to our enjoyment of these things. How appealing and satisfying are some of the beautifully coloured masterpieces of art! Economically too, colour plays a very important role, as shown by the varied colours used in home decorating, clothing, advertising, and the like.

For thousands of years men have known that colourless glass of certain shapes, as well as frost, diamonds and other crystals, produce light of many colours when illuminated by white light. Until the time of Sir Isaac Newton everyone supposed that the glass or crystals produced the light by giving something to the light as it was reflected by, or transmitted through, them. It was he who, after thorough scientific investigation arrived at the true explanation of the nature of colour and the character of white light.

11 : 43 COMPOSITION OF WHITE LIGHT

(a) Dispersion

In 1666, Newton permitted a beam of sunlight, passing through a circular hole in a window blind, to fall on a triangular glass prism. He found that the light was refracted or deviated, from its original path. Instead of obtaining a simple image of the hole, he obtained a band of colours which he called a **spectrum**. Its colours were the same as those found in the rainbow—red, orange, yellow, green, blue and violet, with each colour merging imperceptibly into the next (Fig.

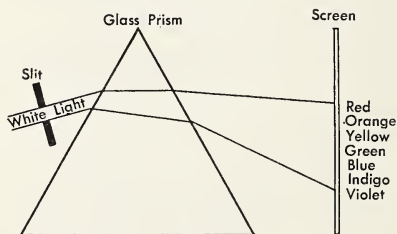


Fig. 11:1 Dispersion of White Light into its Spectrum.

11:1). Newton reasoned that white light must be composite, that is, made up of a combination of the above colours. The separation of the colours by the prism he called **dispersion**. A further study of dispersion is made in experiment 16, chapter 13.

As shown in Fig. 11:1 this dispersion occurs because the different colours are refracted different amounts by the prism and are deviated different amounts from their original direction. Red is always bent the least from its original direction and violet the most, with the other colours intermediate between these.

As we learned earlier (Sec. II:29), refraction is caused by a change in velocity of light on passing from one medium to another. In free space, or in air, light of all colours travels at the same rate, 186,000 miles per second. On entering an optically denser medium such as glass the light is slowed down, and on leaving this medium it speeds up to regain its original velocity in air. Since the different colours are bent different amounts by the prism, it follows that they must be travelling at different velocities through the prism. Red light, bent the least, must slow down the least on entering the prism and therefore speeds up the least on leaving. In contrast, violet light must slow down the most on entering, and speed up the most on leaving the prism.

A question that immediately arises of course is, "Why does the prism have this different effect on the different colours?" The answer relates back to our wave theory of light (Sec. II:7). The different colours of light result from different wave-lengths.

Red light has the longest waves and violet the shortest, the wave-lengths of the other colours being between these two. Evidently, the longer red rays encounter less opposition to their passage through the glass prism and, therefore pass through more rapidly than do the violet rays.

TABLE OF WAVE-LENGTHS*

(1 Angstrom ($\text{\AA}$) = 10^{-8} cm.)

Infra-red above 7000 $\text{\AA}$

Red	6500 $\text{\AA}$	} Visible Spectrum
Orange	6000 $\text{\AA}$	
Yellow	5800 $\text{\AA}$	
Green	5200 $\text{\AA}$	
Blue	4700 $\text{\AA}$	
Violet	4100 $\text{\AA}$	

Ultra-violet below 4000 $\text{\AA}$

* The wave-length shown for each colour is representative only. Each colour consists of wave-lengths that merge into those of the colours adjacent to it. For example, the wave-lengths of red lie between 6470 $\text{\AA}$ and 7000 $\text{\AA}$.

Colour bears the same relation to light that pitch does to sound. The pitch of a sound depends upon the number of vibrations per second that reach the ear. Similarly the colour of light depends upon the number of vibrations per second that reach the eye. In light, however, since the frequency is so great, it is customary to describe the colour in terms of wave-lengths, rather than in terms of vibration frequency.

Example

Calculate the vibration frequency of red light.

Velocity = 3×10^{10} cm. per sec (Sec. II:6).

Wave-length = 6500 $\text{\AA}$ = 6500×10^{-8} cm.

Velocity = Frequency $\times$ Wave-length

$\therefore$ Frequency = Velocity $\div$ Wave-length

$$= \frac{3 \times 10^{10}}{6500 \times 10^{-8}}$$

$$= .46 \times 10^{15}$$

$\therefore$ The vibration frequency of red light is $.46 \times 10^{15}$ vibrations per second.

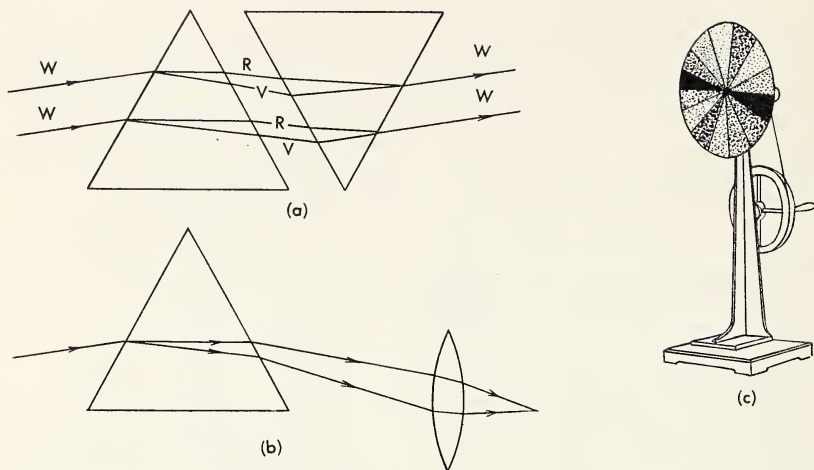


Fig. 11:2 Recombination of the Spectrum into White Light. (a) By Reversed Prisms. (b) By a Converging Lens. (c) By Newton's Disc.

(b) *Recomposition*

Newton further supported his theory concerning the composite nature of white light by showing that the colours of the spectrum could be recombined, giving white light (Chap. 13, Exp. 17). He first arranged two prisms with their refracting edges in opposite directions. On passing white light through these reversed prisms, white light was obtained through them. Fig. 11:2a shows that the first prism disperses the colours, while the second prism recombines them by reversing the original refraction and causing the light waves to be superimposed on each other. A similar effect can be secured by using a converging lens to catch the dispersed coloured light from a prism. If this light is brought to a focus on a screen a spot of white light will be obtained (Fig. 11:2b). If the screen is moved beyond the focus, a reversal of the original colours will be obtained.

Newton also prepared a colour disc on which were coloured sectors whose sizes and colours corresponded fairly closely to the coloured bands obtained in a pure spectrum of white light (Fig. 11:2c). If this disc is strongly illuminated and rapidly rotated it will appear white. This phenomenon is due to what is called "the persistence of vision". Any visual impression on the retina of the eye persists for a short period of time after the cause has been removed. It is on this principle that movies are made to appear continuous. In reality, each picture is thrown on the screen for a fraction of a second, its image persisting in our vision until the next appears. Similarly, if the coloured disc is rotated rapidly enough, the impression produced by one colour persists, while impressions produced by all the other colours are received on the same portion of the retina. Thus all the colours of the spectrum will be superimposed on the retina, and will give the sensation of white light.

II : 44 THE RAINBOW

The rainbow is a spectrum of sunlight formed by water droplets. A ray of sunlight entering a drop of water is refracted at *A* (Fig. 11:3a), the violet rays being refracted more than the red rays.

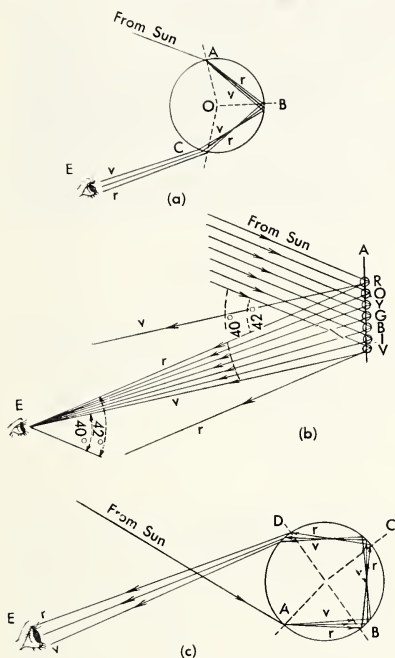


Fig. 11:3 The Rainbow

- (a) Refraction and Total Reflection in a Raindrop.
- (b) The Primary Bow.
- (c) Double Reflection to Produce the Secondary Bow.

The refracted light is totally reflected at *B* and is again refracted at *C* so that the different colours are dispersed. Each drop of water forms its own little spectrum. In the actual bow which the observer sees, the red rays come at an angle of 42° from drops of water higher

in the sky, and the violet rays come at an angle of 40° from drops of water lower in the sky (Fig. 11:3b). The other colours come from drops between these angles. The rainbow has the shape of a bow, since the eye of the observer is at the apex of a cone from which he sees the coloured rays refracted from drops, all of which must subtend approximately the same angle at the eye (between 40° and 42°).

Sometimes a larger, but fainter secondary bow is seen above the primary. The colours in it are reversed, the violet being on the outside. The light enters the lower part of the water drops, is refracted, and twice totally reflected before it leaves the drop (Fig. 11:3c). The light is refracted from the drops of water at angles of from 51° to 54° . The double reflection not only reverses the colours, but also absorbs more light thus causing the secondary bow to be fainter than the primary bow.

II : 45 BEYOND THE VISIBLE SPECTRUM

So far in our study of the spectrum we have considered only those radiations to which the eye is sensitive. Actually the spectrum of sunlight extends well beyond its visible limits. Sir William Herschel, in 1800, on placing the blackened bulb of a thermometer in the various parts of the spectrum, discovered that the heating effect observed at the red end was continued when the thermometer was placed well beyond the visible limit. He thus indicated the existence of a wide range of invisible radiation beyond the red end of the spectrum. These **infra-red** radiations, as they are called, convey almost half of the sun's total outpouring of energy into space. They can penetrate mist, smoke and haze and hence are very suitable for distance photography, reconnaissance, photography in the dark, and detection of forgeries or sub-

Electromagnetic Wave Spectrum

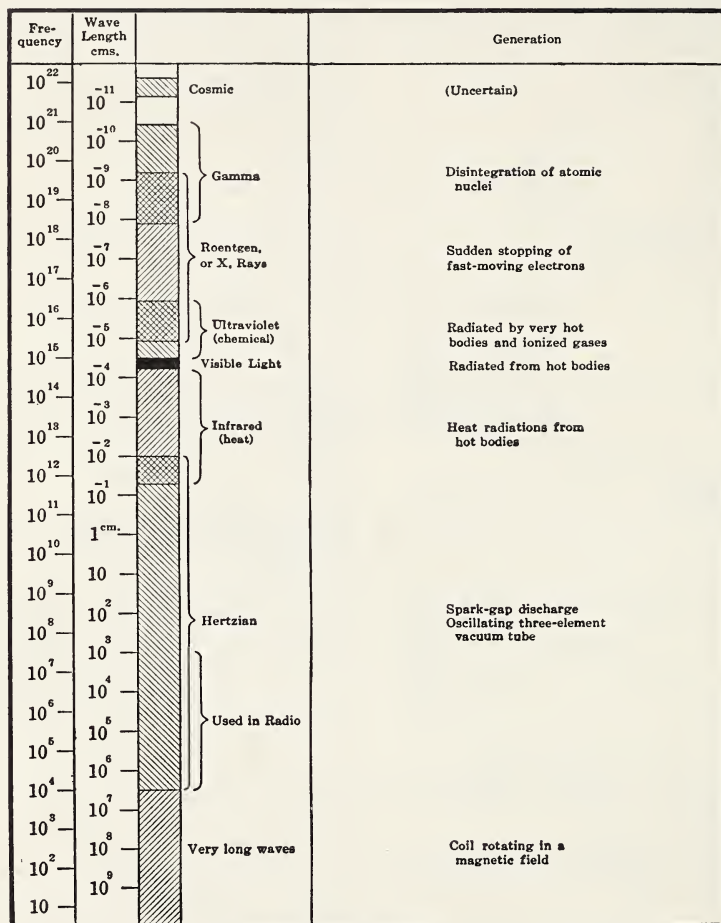
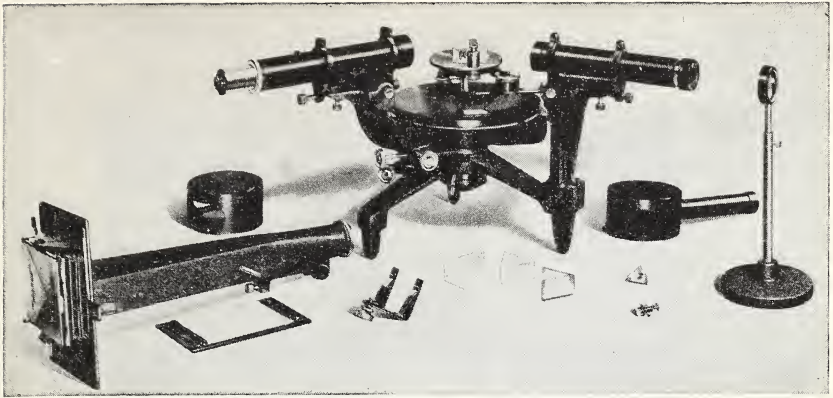


Fig. 11:4

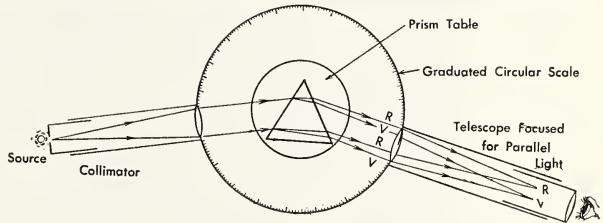


(a)

American Optical Company (Canada) Ltd.

Fig. 11:5

- (a) Spectroscope.
(b) Optical System of Spectroscope.



(b)

stitutions. Under these conditions special photographic film sensitive to infra-red must be used. These rays also have therapeutic value such as in the treatment of rheumatism and other aches and pains.

The year following Herschel's discovery of the infra-red, Ritter discovered, by its action in blackening certain silver salts, a band of invisible radiation beyond the violet, called the **ultra-violet**. Ultra-violet rays do have special photographic effects, and also make some substances such as vaseline and certain minerals "fluoresce" or give out "cold light". They have a highly beneficial effect on health, accelerating the manufacture of vitamin D under the skin. These ultra-violet rays are easily absorbed by mist, smoke and ordinary glass. Consequently, one readily recognizes the

value of a holiday away from the city. For ultra-violet treatment one must be exposed directly to the sun's rays, or use windows of special "vita glass" which is transparent to some ultra-violet rays. Proper precautions must be taken as overtreatment can produce severe sunburn, as well as damage to the retina of the eye. Ultra-violet lamps simply consist of carbon or mercury electrodes between which an electric current produces an arc. Such lamps are usually fitted with quartz lenses which are transparent to the ultra-violet rays.

The presence of ultra-violet rays beyond the visible spectrum of white light may be shown by using a quartz prism in place of the glass prism in Fig. 11:1. If a sample of anthracene is placed beyond the violet it will be seen to fluoresce.

In addition to the invisible radiations

discussed above in connection with the solar spectrum, there exist other invisible radiations such as radio waves, X-rays, and gamma rays (rays emitted by radioactive substances). All these different radiations are propagated as waves with the same velocity as light, the difference in their properties being due to their different wave-lengths. The relationship between these various electromagnetic waves, as they are called, is shown diagrammatically in Fig. 11:4.

11: 46 SPECTRUM ANALYSIS

The spectroscope is an important instrument by means of which the spectra of luminous bodies can be produced and measured. It consists of a tube called the collimator (Fig. 11:5), at one end of which is a convex lens and at the other end an adjustable vertical slit. The length of the tube is equal to the focal length of the collimator lens, so that when the slit is illuminated by light from the source, S , under examination, a parallel beam can be directed onto a prism situated on a small turn-table at the centre of the instrument. The dispersed beams produced by the prism are received by a telescope focused for parallel light and fitted with cross-wires. This telescope can be moved round a circular scale against which the deviations of the constituent parts of the spectrum formed can be measured. The examination in this way of the light from different luminous bodies reveals that each spectrum is characteristic of the source, and a study of these spectra yields much valuable information to the physicist and astronomer. Accordingly we shall briefly consider here some of the more important spectra and their significance (Fig. 11:6).

Continuous Spectra: These consist of a number of coloured bands each shading off gradually into the next. They

are produced by incandescent solids, e.g., arc-lamps, white-hot iron, etc.

Line Spectra: Incandescent gases and vapours emit light which when analysed produces spectra consisting of a number of well-defined coloured lines or coloured images of the slit. Each element has its own characteristic line spectrum which provides a certain and accurate means of identifying the element (Exp. 18, Chap. 13). The presence of even a minute quantity of an element in a mixture can be detected by spectroscopic analysis, and it is interesting to note that the method has been the means of discovering new elements. If the spectrum of a substance contains lines which do not correspond with those of any known element, the obvious conclusion is that there is present an element as yet not known. In this way the elements caesium and rubidium were discovered by Bunsen.

Line spectra can be produced by the Bunsen flame only in the case of substances which are easily vaporized. Other substances must be vaporized, using an electric arc or a spark dis-

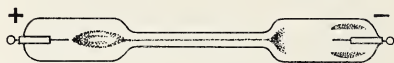


Fig. 11:7 An Electrical Discharge Tube.

charge. The spectra of incandescent gases are usually obtained by means of special tubes containing a sample of the gas at low pressure through which the discharge from an induction coil is passed (Fig. 11:7).

Absorption Spectra: If a sodium flame is set up between the slit of a spectroscope and a high-power electric lamp (Fig. 11:8), a dark line will be observed in the continuous spectrum of the light from the relatively hotter lamp in a position corresponding to that of the

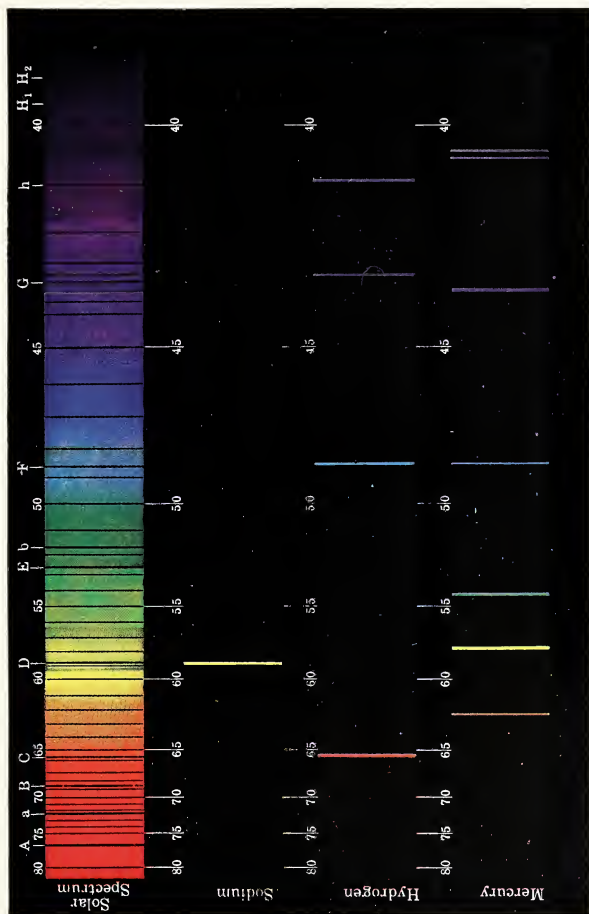


Fig. 11:6 Spectrum Chart Showing Absorption Spectrum or Dark-Line Spectrum of the Sun, and Bright-Line Spectra of Sodium, Hydrogen and Mercury. Note: A Continuous Spectrum is identical to the Solar Spectrum without the dark lines.

Adapted from Erdmann's "Lehrbuch der Anorganischen Chemie."

yellow line of the incandescent sodium vapour. With other vapours dark lines would be formed in positions corresponding to their line spectra. A spectrum

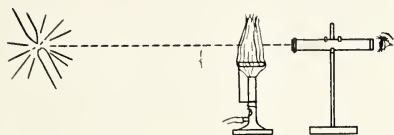


Fig. 11:8 The Production of an Absorption Spectrum.

crossed by dark lines in this way is called an absorption spectrum, and it was found that all substances when interposed in the path of light originating from a higher temperature source absorb from it light of the same wave-length that they themselves emit.

The Solar Spectrum is an absorption spectrum containing hundreds of dark lines carefully studied by Fraunhofer in 1814. These lines are due to selective absorption from the radiation emanating from the extremely hot core of the sun by the relatively cooler gases in the sun's atmosphere. Most of the lines have been found to correspond to lines in the spectra of elements present on the earth, and we have thus good grounds for believing that the chemical components of the sun and the earth are similar. A certain group of lines did not correspond with those of any known element. They were accordingly attributed to an element which was named helium, and which was ultimately discovered on the earth twenty-six years later. The constitution of the stars is determined in a similar way from an examination of their absorption lines.

II : 47 NATURE OF COLOUR

(a) Colour

We have already established that colour is a property of light waves (Sec.

II:43). It may be defined generally, as the response of vision to different wave-lengths of light. Colour is the alphabet in our visual language, through which we make interesting our description of things and ideas which otherwise would be dull and prosaic. Our present knowledge and use of colour is based largely on the sciences of psychology, chemistry, and physics.

Psychology considers colour through the physical operation of the eye and the mental impression created by colour on the brain. As a result, the actual perception of colour is a highly personal experience which may be influenced by such factors as health, fatigue and response of the eye to colour (colour-blindness). According to psychologists the average person recognizes four distinct primary colours, red, yellow, blue and green. Colours do have a strong influence on people. Tensions can be heightened or relaxed through a change in colour harmonies; a feeling of warmth or coldness can be obtained by colour schemes used; colour can be stimulating or restful, it can attract or it can repel.

Chemistry deals with the production of materials which have the ability to absorb or reflect part of the light which falls upon them. These are chiefly dyes and pigments. The explanation for the colours of these materials is given in part (b) below.

Physics deals with colour from the standpoint of differences in wave-lengths of the coloured lights, and the effects of superimposing these on one another. The additive theory of colour to explain these effects is discussed in part (c) below.

These three colour theories are the basis for our modern usage of colour. Though separate, they are also interdependent. The range and intensity of the colours we see depend upon the quality and quantity of light, the nature of the

surface visible, and our ability to see and interpret what meets our eyes.

(b) Colour of Objects— The Subtractive Theory

There are three colours, yellow, red, and blue, which in pigments are the source of all other colours. By mixing these three colours in the right proportion, all other colours may be obtained. No mixture of other colours will produce any of these three colours. For this reason yellow, red, and blue are called **primary colours**. A colour chart has been prepared (Fig. 11:9) in which these primary colours are placed the

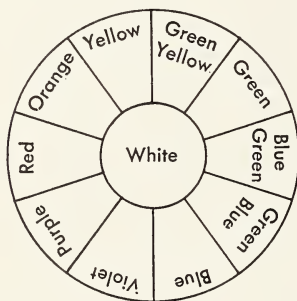


Fig. 11:9 A Colour Chart

same distance apart along the edge of the circle. Mixing any two primary colours produces a third colour called a **binary colour** which is intermediate between those primaries, e.g., yellow and red produce orange. Various hues can be produced by mixing a binary colour with a primary colour used in making the binary, e.g., yellow and orange produce yellow orange. Certain colours seem to strengthen each other when they are seen together, and hence are said to be **complementary** to each other. In the chart the colours on the opposite sides of the circle are complementary.

White is the total addition of colour,

and not, as often believed, the absence of colour. It is produced when a surface reflects all colours equally. Black, on the other hand, is perceived when a surface absorbs all colours and reflects none. Colour, then, is the result of partial absorption, and consequent subtraction, of a band of colour from the spectrum. The surface of an object will appear red when it is of such nature that it absorbs all but the red wave-lengths of the spectrum, and reflects these red wave-lengths (Chap. 13, Exp. 19). When we mix pigments, each one subtracts certain colours from white light, and the resulting colour depends upon the light that is not absorbed. For example, if we mix a blue pigment with a yellow one we get a green colour. The blue subtracts or absorbs all colours from white light, except green, blue and violet, while the yellow subtracts all except green, yellow and orange. Green is the only colour not subtracted by either pigment. For this reason the two pigments produce green.

Similarly, transparent objects are able to absorb or subtract certain colours from white light. If white light is passed through a piece of red glass, the glass absorbs all light except red, and a little orange, and we obtain red light (Fig. 11:10a). Objects that are transparent to only one colour are called **colour filters**. The combination of a yellow and a blue filter placed over a single white light source will result in a green light because all except the green wave-lengths of the spectrum have been absorbed (Fig. 11:10b). Similarly a combination of three filters, each corresponding to a primary colour, will absorb all the colours and allow practically no light to pass (Fig. 11:10c). (Chap. 13, Exp. 19).

The light which falls upon an object can also determine its colour. If the light does not contain all the colours of

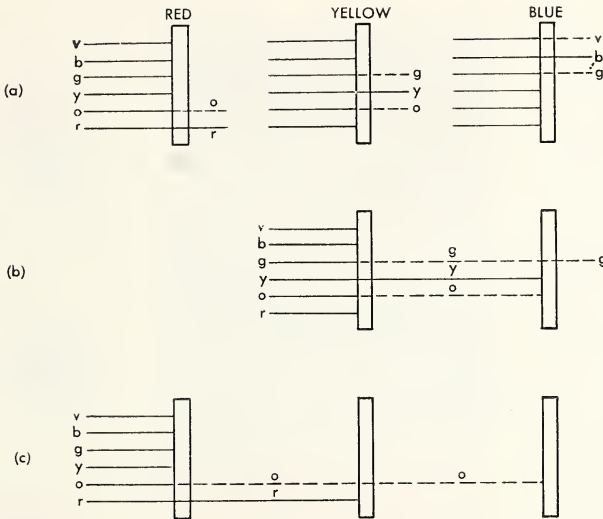


Fig. 11:10 Colour Filters (The Subtractive Theory)

- (a) Transmission of Light by Different Coloured Filters.
- (b) Combination of Yellow and Blue.
- (c) Combination of Red, Yellow, and Blue.

the spectrum then the true colour of the object will not be observed. The light given off by a light bulb does not contain all the colours found in sunlight. For this reason an article of clothing may appear quite different in the sunlight than when seen under artificial light.

(c) Coloured Lights— The Additive Theory

Having produced different coloured lights by the use of filters, two or more of these may be added together to produce still other colours. The three colours, red, green and blue, which combine to produce white are called the three **primary colours** for lights. None of these primary colours can be produced by adding other colours of lights. However, any other colour can be pro-

duced by a proper combination of them (Fig. 11:11). For example, red and blue light when combined produce violet; red and green light added together

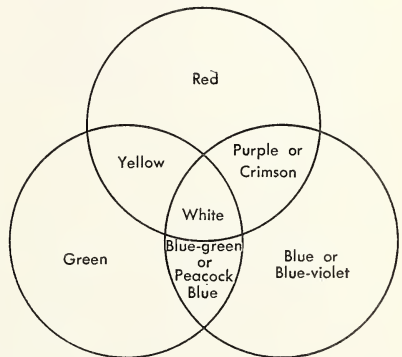


Fig. 11:11 Coloured Lights (The Additive Theory).

will produce yellow, and so on. The colour resulting from the simple combination of each pair of primary colours is complementary to the third primary; for example, violet is complementary to green, and yellow is complementary to blue. If we superimpose these complementary coloured lights we again get white light.

Contrast how colour is obtained in mixing pigments with how it is obtained in mixing coloured lights. In the former the resulting colour is the one not absorbed or subtracted by either pigment (the subtractive effect); in the latter the resulting colour is obtained by adding the effect of the individual colours (the additive effect). Both methods are widely used in industry. The mixing of pigments to produce our multi-coloured paints, the many vegetable and synthetic dyes for treating fabrics, textiles, etc., and the use of filters in photography, all are applications of the subtractive effect mentioned above. The additive effect is applied in the use of coloured spotlights to illuminate actors on stage, or participants in a carnival or pageant, as well as to produce changing and spectacular effects in the illumination of Niagara Falls and in some of the coloured advertising that is so common nowadays.

Colour is of tremendous importance in industry. Its use in advertising has been mentioned above. Bright contrasting colours of paint on walls, floors, and machinery not only provide better visual conditions but also boost morale, speed up production, and affect safety records. Colour codes are used in business for invoicing, in electrical industries to denote polarity, voltage, resistance, and the like, and in shipping to encourage due precautions in the handling of dangerous articles. All, of course, are familiar with its use in traffic control.

(d) *Colour Vision*

The way in which light is changed into the sensation of sight is not definitely known. The most widely accepted theory, the Young-Helmholtz theory, states there are three sets of colour nerves in the normal eye. One of these sets of nerves responds only to blue light, another set to green light, and the third set to red light. The colour of an object is determined by the relative degree of stimulation of each type of nerve.

A small proportion of men (about $3\frac{1}{2}\%$) and women (about $\frac{1}{2}\%$), do not have all three of these sets of colour nerves and hence they do not receive the same sensation of colour from an object as a person with all three sets of colour nerves. Such people are said to be colour blind. By this we do not mean that they do not see colour in objects, but that they do not see the same colours as a person with normal eyes. This defect is inherited through the mother; it usually exists from birth; and there is no known cure for it.

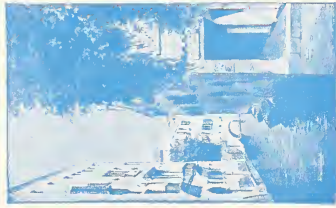
Because a colour-blind person sees a different colour pattern in a landscape from the pattern seen by a person having normal vision, colour-blind observers are very efficient in detecting camouflage and are so used during wars. Some colour-blind persons are unable to distinguish reds and greens from each other and, consequently, have real difficulty with traffic signals.

II : 48 COLOUR PRINTING

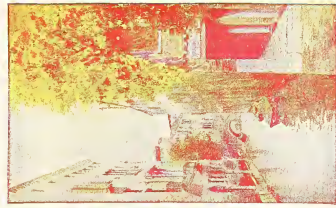
Most of the coloured pictures in books and magazines are made by using four separate printing-plates, each plate printing a different coloured ink on white paper—yellow, red, blue and black, in that order. The plates are made from four photographic negatives of the same subject. These negatives are made through fine-meshed coloured filters,



5



4



3



2



1

Fig. 11:12 Three-Colour Process of Printing.

1. Yellow Plate, negative made through a green-yellow filter; 2. Red Plate, negative made through a red-yellow filter; 3. Red on yellow; 4. Blue Plate, negative made through a red-yellow filter; 5. Yellow, Red, and Blue combined. Notice the various colours and shades in the finished print. Note: In Four-Colour Printing a Black Plate is Used in Addition to the Yellow, Red and Blue Plates.

each stained with one of the three primary colours (the black one is not actually used in the creation of the coloured picture in Fig. 11:12). The fine-meshed filter breaks the subject into numerous small dots on the negative. The filter determines what colours can pass through the camera and become recorded on the negative. Thus dots representing only certain colours are recorded on each negative. The first plate reproduces the dots of the first negative in yellow ink on white paper. The second plate reproduces those of the second negative in red ink on or between the yellow dots, etc. The final effect is one of individual and overlapping dots of colour. Where a dot of one colour overlaps a dot of another colour a new colour may be obtained. The eye blends these dots of the four original and the mixed colours to give the total effect.

II: 49 CHROMATIC ABERRATION

Since the action of a convex lens is similar to that of two prisms with their bases in contact (Sec. II:35), incident rays, in addition to being deviated to form a convergent beam will be dispersed on passing through the lens. The various colours are brought to different foci on the principal axis, the focus for violet rays being nearer the lens than that for red rays (Fig. 11:13a). In consequence it is impossible to obtain a well-defined image when white light is used, the image received on a screen having a red fringe when placed at *A* and a blue fringe when placed at *B*, there being no position be-

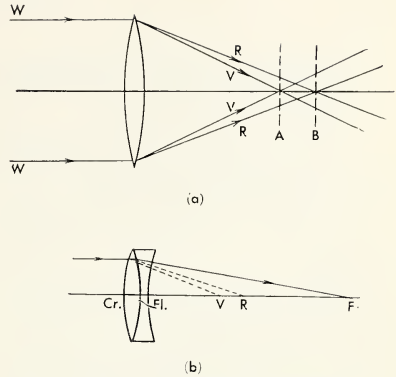


Fig. 11:13 Chromatic Aberration.

(a) Its Cause.

(b) Its Correction—An Achromatic Lens.

tween *A* and *B* at which the image is sharply in focus. This non-focusing of light of different colours is known as **chromatic aberration**. By using two reversed prisms, one of crown glass and the other of flint glass which has a higher index of refraction, it is possible to obtain a non-dispersive combination which still has the power of deviating the light (Fig. 11:13b). Similarly it is possible to combine a convex lens of crown glass with a weaker concave lens of flint glass so that the dispersion produced by the two lenses is equal and opposite. A lens combination of this type is called an **achromatic** (without colour) lens. These achromatic combinations are still converging and accordingly can be used as objective lenses in telescopes, field glasses, cameras, and other optical instruments.

II : 50

QUESTIONS

1. (a) Define: spectrum, dispersion.
(b) Why does a prism deviate violet light more than red light?
(c) Calculate the vibration frequency of violet light (See table, p. 111, for wave-length of violet light).
2. Describe and explain three methods for recombining the spectral colours into white light.
3. Explain how refraction produces a solar spectrum (rainbow).
4. Write a note on (a) infra-red rays, (b) ultra-violet rays, indicating,
 - (i) how each differs from visible light.
 - (ii) how each can be detected.
 - (iii) how each is used.
5. (a) What is the purpose of a spectro-scope?
(b) Distinguish a line spectrum from (i) a continuous spectrum, (ii) an absorption spectrum. How is each produced?
6. What is the physicist's explanation of (a) coloured light, (b) white light?
7. (a) In the subtractive theory of light what are (i) the primary colours, (ii) complementary colours?
(b) Why does a rose appear red, grass green and a dandelion yellow when seen in sunlight? State a general rule for the colour of an opaque object.
- (c) Why does red glass appear red, blue glass appear blue, and ordinary glass appear colourless, in white light? State a general rule for the colour of transparent objects.
(d) What would be the colour of the objects in (b) when viewed through (i) a red-glass filter, (ii) a blue-glass filter?
(e) Why is it unwise to buy coloured clothing by artificial light?
8. (a) How does the additive theory of light differ from the subtractive theory?
(b) In the additive theory what are (i) the primary colours, (ii) complementary colours?
(c) If coloured spotlights are shone on a white screen,
(i) what colour will be obtained if red and blue lights are used?
(ii) what coloured lights should be used to produce yellow?
9. How does the physicist account for the difference between mixing coloured lights and coloured pigments?
10. What is colour-blindness? How does the Helmholtz theory explain it?
11. Describe the process of colour printing.
12. (a) What is chromatic aberration?
(b) What is an achromatic lens?

12:51 THE CAMERA

The photographic camera is essentially an enclosed box or bellows chamber with an opening or aperture in the front through which light from an object passes. The image is recorded on a light-sensitive material at the back.

(a) History

The evolution of the camera is credited to men like Roger Bacon, 1267, and Leonardo da Vinci, 1519, who described and developed the pin-hole

camera. Baptista Porta, 1553, and Johann Kepler, 1604, later added a lens and then a combination of lenses. From these simple beginnings have come many types of cameras ranging from the relatively inexpensive family-type cameras, through the more expensive press and movie cameras, up into the highly specialized cameras used in television and in aerial photography.

(b) Structure

All cameras are constructed on the same basic principles as were the first crude, wooden, box-cameras. The essential parts of a camera (Fig. 12:1) are:

1. A light-tight box or bellows.
2. A lens to form the image on the film.
3. A shutter (and diaphragm) to con-

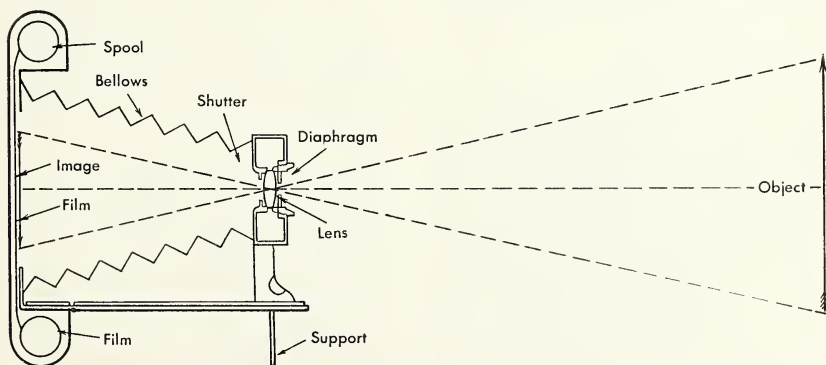


Fig. 12:1 The Essential Parts of a Camera and How it Forms an Image.

trol the amount of light that is admitted to the film.

4. A negative holder or carrier to hold films in position during exposure.
5. A view-finder or ground glass to determine picture area.

By the addition of special accessories and other refinements, the utility and scope of the camera may be extended to meet almost any photographic requirement.

(c) Focusing

In order to focus objects at different distances from the camera, the lens is often attached to a bellows so that it may be moved nearer to the light-sensitive plate or film, or farther away. In section II:37 we learned that as the object is moved nearer to a converging lens, the real inverted image gradually moves farther away from the lens. This should indicate how to focus the camera. For distant objects the lens is moved so that the sensitive plate is located at its principal focus. For close objects, the lens is moved away from the sensitive film, for now the image is focused beyond the principal focus of the lens. Most cameras include a focusing scale on the lens mount or on the bed of the camera and many have built-in range finders to assist in focusing.

(d) Light Control

As has been indicated previously the film or plate in a camera contains materials which are sensitive to light. The plate is coated with an emulsion consisting of gelatine and a silver salt. Light decomposes this silver salt so that when "developed" and "fixed" a negative is obtained consisting of a dark deposit of silver in places corresponding to the light parts of the original image, and light transparent portions in positions corresponding to the darker parts of the original image.

One sees, therefore, that it is necessary to be able to control the amount of light that enters the camera. This is done in two ways: (1) by controlling the size of the aperture or opening through which the light enters; and (2) by regulating the length of time that the light is permitted to enter. The former is accomplished by using a variable diaphragm behind the lens which enables the aperture to be varied, and the latter by means of a shutter, which is a delicate mechanical device, often consisting of a number of overlapping thin metal blades, held in position by means of springs. On being released or tripped, when taking a picture, the shutter opens and closes for a measured time interval.

When using a small aperture a longer exposure is required than with a large one. It is wise practice to use as small an aperture as possible as this permits using the central part of the lens only, and prevents errors due to inaccuracies near the edges of the lens. Also greater depth of focus is obtained, that is, objects at relatively smaller and greater distances from the camera will still be sufficiently in focus to look clear in the print.

II : 52 THE HUMAN EYE

The eye is the sense organ enabling light to be perceived. This, the most wonderful of all optical instruments, can be compared in many respects to a camera (Fig. 12:2).

(a) Structure and Action

The eyeball is approximately spherical in shape and slightly less than one inch in diameter (Fig. 12:3). The wall of this sphere is composed of two major layers: (1) the outer covering, the *sclerotic coat*, is a tough opaque white substance forming the white of the eye. The front portion of this sclerotic coat forms a transparent, curved section called the

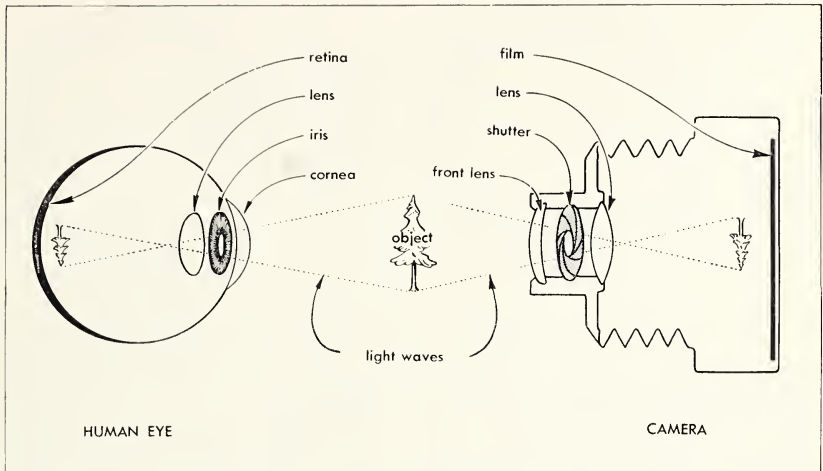


Fig. 12:2 Comparison of the Eye and the Camera.

cornea that protects the eye and aids in refracting light. (2) The inner layer, the **choroid coat**, is black to prevent internal reflection and to protect the light-sensitive parts of the eye. It is also largely nutritive in function. The aqueous and vitreous **humours** are jelly-like materials filling the spaces within the eyeball, which help to keep its spherical shape.

Behind the cornea is a coloured diaphragm called the **iris**. This is really an

extension of the choroid coat, and its colour is mainly due to the variable amounts of pigment in it. In the centre of the iris is a circular aperture, called the **pupil**, which appears black due to the black interior of the eye. The iris contains muscles, which dilate and contract the pupil adjusting the eye to different amounts of light. The pupil is dilated in dim light, and contracted in bright light. This action occurs involuntarily, i.e., without any control on our part, and hence is called the **iris reflex**. To note its action, stand in front of a mirror in a dark room for several minutes. Then turn on the light and note the immediate contraction of the pupil. Optometrists use drugs, such as atropine, to temporarily dilate the pupil and permit internal examination of the eye.

Behind the pupil and iris is the **crystalline lens**. This is a transparent structure, made up of numerous concentric layers, increasing in density toward the middle.

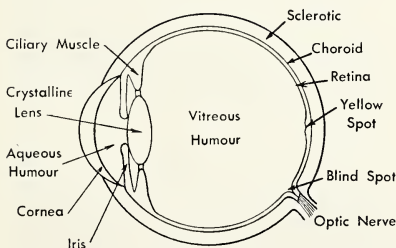


Fig. 12:3 The Structure of the Eye.

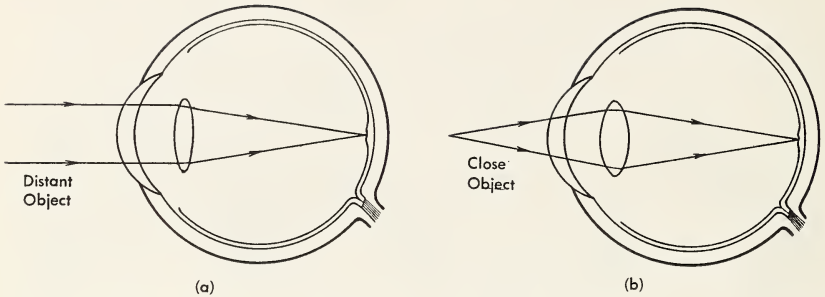


Fig. 12:4 Lens Accommodation. (a) Distant Vision (b) Close Vision.

The curvature of its front surface is considerably less than that of the back surface. Both of these features tend to diminish distortion of the image. The lens is encased in an elastic capsule and is held in place by suspensory ligaments which are attached to the choroid coat. These ligaments hold the lens under a certain tension so that it normally tends to be flattened and adjusted for distant vision. In the choroid layer near the suspensory ligaments are small ciliary muscles. The contraction of these muscles tends to relieve the tension exerted by the suspensory ligaments on the lens which therefore becomes more convex and so adjusted for close vision. The adjustment of the lens to form a sharp image on the retina is called **accommodation** (Fig. 12:4). The normal eye can accommodate itself to objects ranging from infinity to a point about twenty-five centimeters or ten inches from the eye. This latter point is known as the nearest point of distinct vision. Objects closer to the eye than

this cannot be clearly focused by the unaided eye.

The **retina** is the innermost layer of the eye and is sensitive to light. The retina is composed of visual cells, nerve cells, and the fibres which connect these and conduct the nerve impulses to the brain. The visual cells are of two-types, called rods and cones, so named because of their characteristic rod and cone shapes. The rods are concerned with colourless and dim-light vision, while the cones handle colour and bright-light vision. The nerve cells integrate and relay the impulses which they receive, to the optic nerve, and through it to the brain. That part of the retina where the optic nerve enters the eye, is insensitive to light and is known as the **blind spot**. Its existence can be readily demonstrated as shown in Fig. 12:5. The most sensitive part of the retina is a small yellow spot located on the principal axis of the lens. An object being viewed is automatically focused on this area.



Fig. 12:5 The Blind Spot. Close right eye. Hold the book at arm's length. Stare at the X. Move the book toward you. At a certain distance the circle will disappear, for its image is formed on the blind spot.

(b) Defects of Vision and Their Correction

In view of the delicate adjustments made by our eyes and the way we abuse them these days with excessive reading, watching movies, television, etc., it is only natural that many abnormalities or defects develop. Here, however, we are only concerned with defects or errors caused by refraction of light.

When an eye with no refractive error is at rest, parallel rays of light are focused exactly on the retina. Many eyes, owing to abnormalities of the refracting mechanism, do not focus the light exactly on the retina. Such defects of the eye can in large measure be overcome with the aid of suitable lenses (spectacles).

1. Near-sightedness

Persons suffering from this defect are unable to focus on distant objects distinctly, although objects close to the eyes are clearly seen. This is due to the axis of the eyeball being too long or the crystalline lens being too powerful, so that rays from a distant object tend to be focused in front of the retina (Fig. 12:6a). This defect is largely hereditary, but is also aggravated by too strenuous use of the eyes during the early years. Concave lenses placed in front of the eye will make the light more divergent and bring the image to a focus on the retina.

2. Far-sightedness

A far-sighted person cannot see clearly objects close to the eye although distant objects may be distinctly seen. The defect is due to the axis of the eyeball being too short or the crystalline lens not sufficiently converging so that rays from a nearby object tend to converge to a point behind the retina (Fig. 12:6b). It is the most common of refractive errors of the eyes and is present

to some degree in about two-thirds of all adults. Convex lenses placed in front of the eye will reduce the divergence of the rays which can then be focused on the retina.

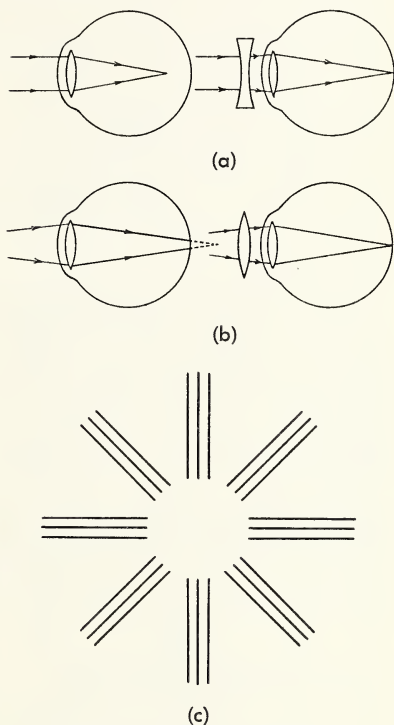


Fig. 12:6 Defects of Vision.

- (a) Near-sightedness, Corrected by Concave Lens.
- (b) Far-sightedness, Corrected by Convex Lens.
- (c) Test for Astigmatism. Do all the lines appear equally distinct to you?

3. Astigmatism

As a result of this defect lines in different planes are brought to different foci and in consequence one set of lines

will be in sharp focus, while others inclined to them are blurred and indistinct (Fig. 12:6c). For example, an astigmatic eye may clearly discern all the vertical lines of a building, while those in a horizontal plane are scarcely perceived. The main cause of this defect is the lack of sphericity of the cornea, in which the vertical section is frequently more curved than the horizontal. To overcome the defect cylindrical lenses are used to assist refraction in the plane of least curvature of the cornea. Astigmatism is present to varying degrees in most eyes.

4. *Presbyopia*

This is a defect of age resulting from the loss of accommodation brought about by hardening of the crystalline lens, or of the ciliary muscles. It is evidenced by both near and far objects being indistinct. Clear vision by the unaided eye is possible over only a very restricted range. Two pairs of spectacles are required by such people, one pair (convex) for reading, and another pair (concave) for distant vision. Both purposes may be served by a pair of bifocal lenses, the top part being used for distance, and the lower part for reading.

II : 53 THE MAGNIFYING GLASS

The apparent size of an object depends on the angle it subtends at the eye. This angle is known as the **visual angle** of the object, and in order to see a small object clearly one instinctively brings it close to the eye, with consequent increase in its visual angle. With the unaided eye there is, however, a limit to which this process can be carried. This is reached when the object is at the nearest point of distinct vision (normally 25 cm. or 10 in.) at which position the object is seen most clearly. If brought within this natural limit the eye cannot accommodate itself to the widely diverg-

ing rays from the object without undue strain. With the use of a short-focus convex lens, however, it is possible to bring the object even closer, thereby enabling it to be seen still more distinctly without straining the eye. The object is placed inside the focus of the lens at such a position that the eye focuses the magnified virtual image formed at the nearest point of distinct vision. The path of the rays by which the eye sees the image is shown in Fig. 12:7.

The magnifying power of such a lens is the size of image on retina when object is viewed through the lens divided

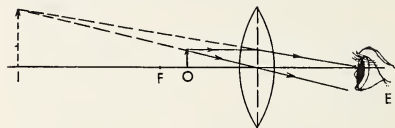


Fig. 12:7 The Action of a Magnifying Glass. The image is focused at the least distance of distinct vision.

by size of image on retina when object is viewed directly at the least distance of distinct vision

$$= \frac{\text{least distance of distinct vision}}{\text{focal length of the lens}}$$

$$= \frac{10 \text{ in.}}{f} \text{ or } \frac{25 \text{ cm.}}{f}$$

In using a magnifying glass we focus the image at the least distance of distinct vision by moving the lens back and forth from the object. A near-sighted person might focus on an image 7 inches from the eye, for example, whereas a far-sighted person would change the lens-object distance so that the image might be 13 inches from the eye. If $f = 1$ inch., the former person would only get a magnification of $7\times$, whereas the far-sighted person would get a magnification of $13\times$. To save argument the average value for least distance of distinct vision has been set at 10 inches.

Note:

$$\therefore \text{Magnification} = \frac{H_i}{H_o} = \frac{D_i}{D_o} \text{ (Sec. IV:32)}$$

and D_i = least distance of distinct vision
= 10 in. or 25 cm.

and D_o = focal length (f) approximately

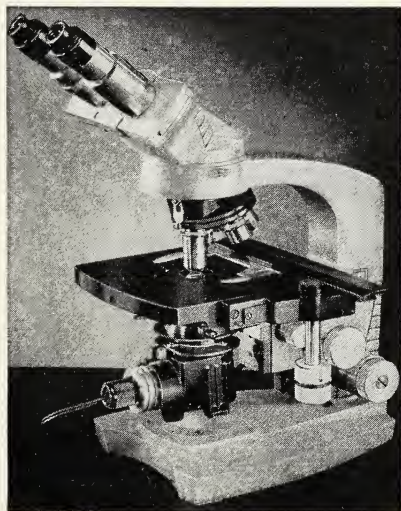
$$\therefore \text{Magnification} = \frac{10 \text{ in.}}{f} \text{ or } \frac{25 \text{ cm.}}{f}$$

II: 54 THE COMPOUND MICROSCOPE

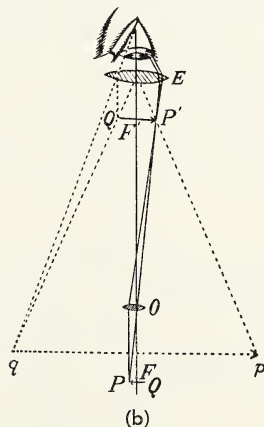
The compound microscope is very widely used to produce great magnifications of small objects. The instrument (Fig. 12:8a) consists mainly of a convex lens of short focal length, called the **objective**, O , and a second convex lens, called the **eyepiece**, E . These lenses are mounted in a tube of adjustable length. The object, PQ , to be viewed is placed just outside the principal focus, F , of the objective (Fig. 12:8b). This produces a real magnified image of the object at $P'Q'$, and this image falls inside the

principal focus, F' , of the eyepiece which acts as a simple magnifying glass. Through this lens the eye sees a large virtual image, pq , when the length of the tube is properly adjusted so that the image is sharply in focus at the nearest point of distinct vision. As with the magnifying glass, the position of the virtual image depends upon the accommodation of the observer's eye.

The magnification produced by the compound microscope is obtained in two stages. Both lenses individually produce a magnified image, so that the total magnification is the product of the two. Microscopes for visual use can be constructed to give magnifications of 2000 and above, the higher magnifications being obtained by using objective lenses of very short focal length. Often such lenses are designed to employ a medium of cedar oil between the specimen and the objective (Oil-Immersion Microscopes). This medium increases the light-gathering power and the resolving power of the objective by reducing reflection and scattering of light at the surface of the lens. Single lenses of very short focal length give images which are



American Optical Company (Canada) Ltd.
(a)



Ray Paths in the Compound Microscope.

Fig. 12:8 The Compound Microscope.

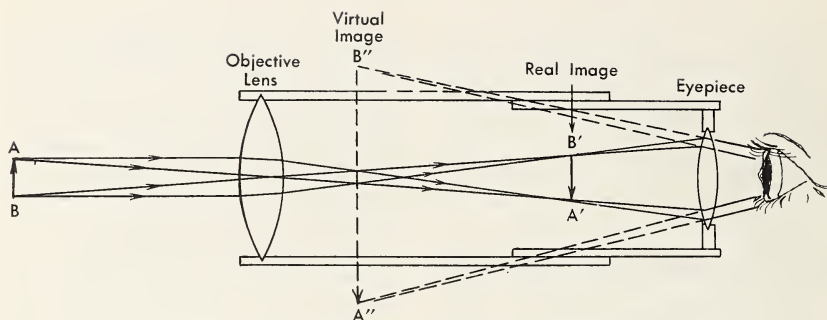


Fig. 12:9 The Refracting Astronomical Telescope.

greatly distorted, and which have coloured edges. To avoid this the objectives of actual microscopes are usually compound achromatic lenses (Sec. II:49).

Microscopes generally have a concave mirror, and frequently a condensing lens above it, to focus sufficient light on the object being examined. The invention of the microscope in 1590 by Zacharias Janssen, with the many improvements added since then, has contributed immensely to the advances made in medicine and public health, as well as revealing many marvels of plant and animal life, and hidden secrets of the mineral kingdom.

II : 55 THE TELESCOPE

(a) Refracting Telescope

The method by which the telescope works is similar to that of the microscope. The refracting telescope consists

of an arrangement of two convex lenses for viewing very distant objects (Chap. 13, Exp. 20). The objective should have a very great focal length, for the greater the focal length the larger will be the image of an object at infinity. It should also be of large diameter to enable a maximum amount of light to be collected, thereby producing a brighter image. This lens will produce a real inverted image at its principal focus. This should be located just within the principal focus of the eyepiece through which the eye sees a magnified virtual image (Fig. 12:9).

The magnifying power of the telescope is approximately equal to the focal length, F , of the objective divided by the focal length, f , of the eyepiece.

$$\therefore \text{Magnifying power} = \frac{F}{f}$$

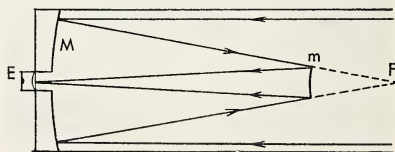
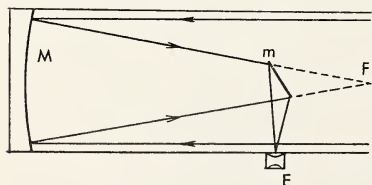
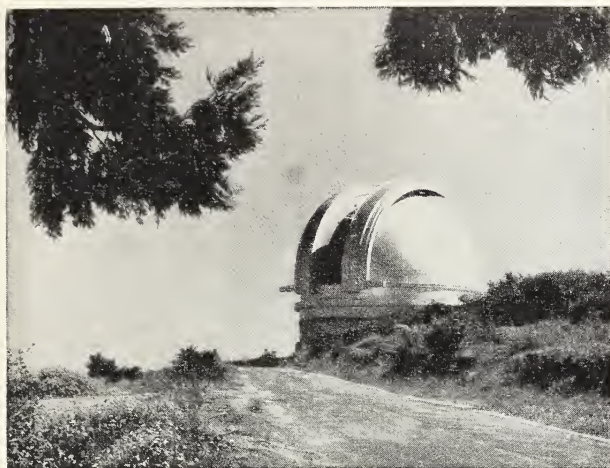


Fig. 12:10 Two Forms of the Reflecting Telescope.



Palomar Mountain
Observatory,
California.

Star Newspaper Service

(b) Reflecting Telescope

Reflecting telescopes are used for astronomical purposes. The objective is a parabolic mirror (Sec. II:26) which collects light from the distant object. Since the light is reflected back toward the object, a means of viewing the image with an eyepiece necessitates the use of an additional mirror or prism (Fig. 12:10).

Large reflecting telescopes include the 74 inch diameter telescope at the David Dunlap Observatory at Richmond Hill, Ontario, and the 72 inch telescope at the Dominion Astro-Physical Observatory near Victoria, British Columbia. Larger

telescopes of this type are located at Mount Wilson, California (100 in.) and at Palomar Mountain, California (200 in.). This latter is the largest telescope in the world, having one million times the light-gathering power of the human eye.

(c) Terrestrial Telescope

The drawback to the astronomical telescope is that the image is inverted. For observing familiar terrestrial objects a telescope requires an image-erecting system. The simplest means of obtaining this is to insert a third convex lens to re-invert the image (Fig. 12:11). Such terrestrial telescopes are used by surveyors, by mariners and by military men.

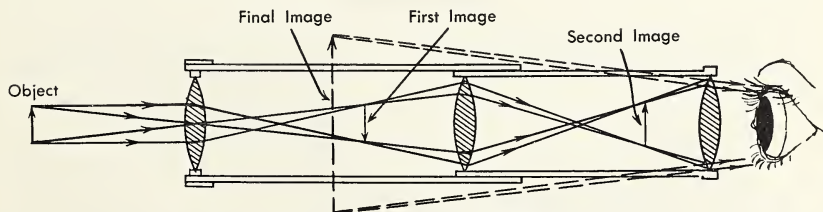


Fig. 12:11 The Terrestrial Telescope.

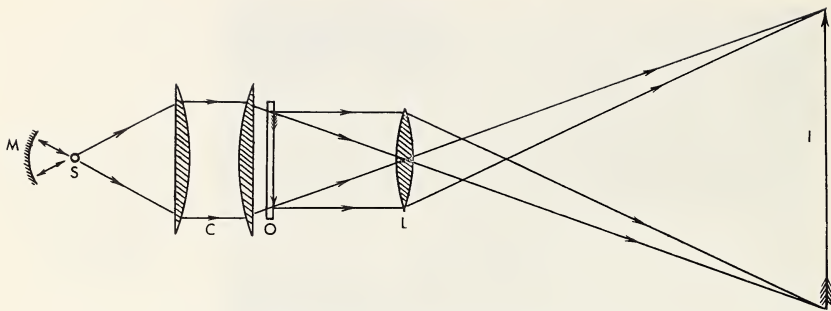


Fig. 12:12 The Slide Projector.

II : 56 THE SLIDE PROJECTOR

The purpose of the slide projector is to cast a magnified image of a slide or coloured transparency upon a screen some distance away. Fig. 12:12 shows the essential structure of such a projector. A study of the paths of the light rays shown in the diagram will serve as an excellent review of some of the work covered earlier in concave mirrors and converging lenses.

For this instrument a very powerful light source is needed. This is placed at the centre of curvature of a concave reflector (mirror) *M*, so that many rays that tend to be lost, on hitting this mirror are reflected back on themselves thereby intensifying the light source. It is also placed at the principal focus of

a condensing lens system, *C*. As a result the diverging cone of rays from the light source on striking this condenser is concentrated into a parallel beam of light and sent through the slide, *O*. The slide must be located outside the principal focus of the objective, *L*. This lens as a result produces a real, enlarged, and inverted image on the screen. The slide is always inserted upside down in the carrier, so that its image will be erect on the screen, *I*. The size of the image may be increased by increasing the distance between the projector and the screen. The objective is contained in a moveable mount, to permit focusing the image for different distances of projection. Optically the motion-picture projector and slide projector are similar.

II : 57

QUESTIONS

1. Compare and contrast the lens camera and the human eye under the following headings:

- (a) structure.
- (b) focusing.
- (c) light control.

2. What adjustments would you make in your camera for taking pictures under the following conditions:

- (a) an object close to the camera.
- (b) an object distant from the camera.
- (c) an object on a cloudy day.
- (d) an object on a sunny day.
- (e) a moving object.

3. The focal length of a camera lens is 3.0 in.

- (a) How far from the film is the lens when a man standing 12 ft. from the

- camera is brought into focus upon the film?
- (b) How tall will be the man's image on the unenlarged picture if his height is 6 ft.?
4. (a) What is meant by (i) iris reflex, (ii) lens accommodation?
- (b) Why do your eyes become more sensitive when you go into a darkened room?
- (c) By means of a diagram show how the lens of the eye changes when the object viewed is moved closer to the eye.
5. Describe, with the aid of diagrams, (a) near-sightedness, (b) far-sightedness, (c) astigmatism, under the following headings:
- (i) cause.
(ii) effect.
(iii) correction.
6. (a) What is the purpose of the magnifying glass?
- (b) Describe the image you see through a magnifying glass.
- (c) Calculate the magnifying power of such a glass having a focal length of (i) 3.0 cm. (ii) 1.5 in.
- (d) What would be the size of the image of a crystal 3 mm. long when viewed through each of the magnifying glasses in 6 (c)?
7. (a) Make a sketch of a compound microscope locating the two images.
- (b) If the first (objective) lens magnifies the object 8 times and the eyepiece magnifies the real image 20 times, how many times is the final image larger than the object?
8. Discuss (a) the refracting telescope, (b) the reflecting telescope and (c) the terrestrial telescope, as to:
- (i) essential parts.
(ii) how each works.
(iii) types of images obtained.
9. In a slide projector:
- (a) Where is the light source relative to (i) the concave reflector, (ii) the condensing lens? Why is it placed in this position?
- (b) Where is the slide relative to the principal focus of the objective lens? In what relative position is the slide inserted in the carrier? Why?
- (c) If the image formed by the projector is too large for the screen should you move the projector closer to the screen or farther away from it? Why? What further adjustment would be necessary?
- (d) The object is 16 mm. high and 50 mm. from the lens. If the screen is 6 metres away, what is the height of the image?

EXPERIMENT 1

To study the characteristics of an image produced by a pin-hole camera. (REF. SEC. II:4)

Apparatus

Pin-hole camera (Fig. 7:3), one large candle, one small candle.

Method

1. With the adjustable section of the camera held stationary so that the ground-glass screen is a fixed distance from the pin-hole, observe the size and other characteristics of the image of the candle placed at some distance from the camera. Move the camera closer to the candle and note the size of the image.
2. Holding the camera a fixed distance from the candle, note the size of the image. Move the adjustable section thereby decreasing the distance of the screen, and hence of the image, from the pin-hole, and again note the size of the image.
3. With the adjustable section held stationary as in step 1, observe the size of the image produced by first the large, and then the small candle at a fixed distance from the camera.
4. If possible, enlarge the pin-hole and note the effect on the brightness and sharpness of the image.

Observations

Record carefully the observations for each of the previous steps.

Conclusions

1. State the characteristics of the image.
2. What effect did each of the following have on the size of the image:
 - (a) decreasing object distance?
 - (b) decreasing image distance?
 - (c) decreasing size of object?
3. Establish the formula:
$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$
4. On what does the brightness of the image and its sharpness of definition depend? Explain fully.

Questions

1. Why do we get an image of the candle and not an image of the pin-hole?
2. What image would be obtained if the hole were increased in size until it has a diameter of 1 in. or more? Why?

EXPERIMENT 2

To prove the Law of Inverse Squares. (REF. SEC. II:11, 14)

Apparatus

Bunsen grease-spot photometer, a set of 5 candles or light bulbs (same size) and candle or light bulb holders.

Method

1. Place one candle at one end of the metre stick and one candle at the other end of the metre stick. Balance the photometer and record the distances of the sources from the screen in the table below.
2. Leaving one candle at one end of the metre stick place two candles at the other end and balance the photometer. Record the distances as in (1).
3. Repeat using three candles against one and record the distances.
4. Repeat using four candles against one and record the distances.

Observations

I_1	I_2	d_1	d_2	d_1^2	d_2^2
1	1				
1	2				
1	3				
1	4				

Conclusions

1. Write the relationship of I_1 and I_2 to d_1^2 and d_2^2 in algebraic form.
2. State the Law of Inverse Squares.

Questions

1. Why does the grease spot appear lighter than the rest of the paper when you look at it toward a light?
2. Why does the grease spot appear darker than the paper when you look at it away from a light?
3. Why does the grease spot seem to disappear when the photometer is balanced?

4. Why should the room be darkened in using the grease-spot photometer?
5. Is the darkening of the room necessary in using a Joly photometer? Why?
6. Repeat the above experiment using the Joly photometer and compare the results.

EXPERIMENT 3

To establish the laws of reflection. (REF. SEC. II:16)

Apparatus

Plane mirror, pins, sheet of paper, tack board, ruler, protractor.

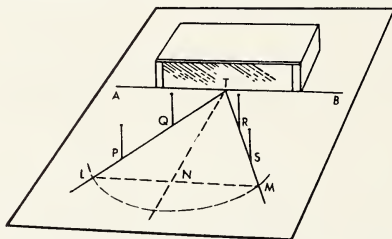


Fig. 13:1

Method

- A. Demonstration Experiment—Optical Disc Method (Sec. II:16).
- B. Student Experiment—Pin Method.
1. Draw a straight line AB (Fig. 13:1). Place the mirror perpendicular to the paper so that its back edge is along this line.
2. Place pins at P and Q about 2 in. apart so that the line PQ strikes the mirror obliquely.
3. Look into the mirror with one eye at the level of the paper and line up the images of P and Q . Insert pins R and S in line with these images.
4. Mark the position of all the pins. Remove the mirror and the pins. Draw the lines PQ and RS . Produce these lines until they meet at T . Through T draw TN perpendicular to AB . With a protractor measure angles PTN and STN .
5. Repeat, with other positions of the pins.

Observations

1.

OBSERVATION No.	ANGLE OF INCIDENCE $\angle PTN$	ANGLE OF REFLECTION $\angle STN$
1.		
2.		
3.		

2. When the incident ray is on the plane of the paper where are the reflected ray and the normal found?

Conclusions

1. State the two Laws of Reflection.
2. Define, and label on your diagram: incident ray, reflected ray, point of incidence, normal, angle of incidence, angle of reflection.

Questions

1. If a polished piece of metal were used as the mirror in the above experiment, where would T be found? Why?
2. Add an observer's eye to the diagram and trace the path of the rays to the eye.

EXPERIMENT 4

To study the position and characteristics of the image in a plane mirror. (REF. SEC. II:18)

Apparatus

Plane mirror, two wooden pegs, paper, ruler, protractor.

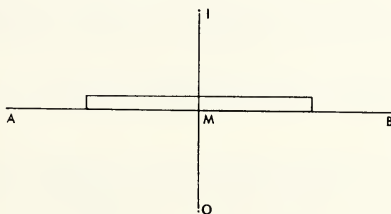


Fig. 13:2

Method

1. Draw a straight line AB in the middle of the sheet of paper. Place a plane mirror perpendicular to the paper, so that its reflecting surface is on AB .
2. Place the object (wooden peg) about 3 in. in front of the mirror. Mark its position O .
3. Look into the mirror to see the image of this object, and using the second wooden peg as a finder place it exactly where the image appears to be. This can be done quite accurately by using the method of parallax. That is, look into the mirror at the image, and over the top of the mirror at the finder. Adjust the position of the latter so that when you move your eye from side to side there is no relative movement between the finder and the image. Mark the position of the image I . Compare the size of the image to the size of the object.

4. Remove the mirror. Join OI and let the line cut AB at M . Measure the lengths of OM and IM , and measure the sizes of the angles at M .
5. Repeat for other positions of the object.
6. Look at yourself in a mirror and raise your left hand. Note what you see.

Observations

1.

OBSERVATION NUMBER	DISTANCE OF OBJECT OM	DISTANCE OF IMAGE IM	SIZE OF ANGLES AT M
1.			
2.			
3.			

2. How does the size of an object and its image compare?
3. Which hand appeared to be raised in the mirror? What term applied to the image describes this phenomenon?
4. What kind of image is it?

Conclusions

1. State your conclusion relating to the position of an image in a plane mirror.
2. Summarize the characteristics of such an image.
3. Define or explain: parallax, lateral inversion, virtual image.

Questions

1. How could you locate geometrically the position of the image of an object in a plane mirror? Show this by a diagram.
2. Include in the diagram an eye, and show the path of the light rays whereby the eye sees the image.

EXPERIMENT 5

To show the location of images produced by two plane mirrors at right angles. (REF. SEC. II:20)

Apparatus

Two plane mirrors, four wooden pegs, paper, ruler, protractor.

Method

Repeat parts 1, 2 and 3 of experiment 4 using two plane mirrors placed at right angles to each other.

Observations

Describe the number and location of the images.

Conclusion

Construct a diagram to show how the images were obtained.

Questions

1. Add an observer's eye to the above diagram and trace the path of the rays to the eye.
2. Determine experimentally how many images are obtained when the mirrors are inclined at 60° , at 45° , etc. Use your results to verify the formula:

$$\text{Number of images} = \frac{360^\circ}{\text{angle of inclination}} - 1$$

EXPERIMENT 6

To study the action of a concave mirror, and to determine its focal length (f). (REF. SEC. II:21)

Apparatus

Optical bench, concave mirror, candle, screen.

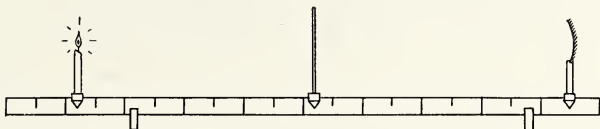


Fig. 13:3

Method

- A. Demonstration Experiment—Optical-Disc Method (Sec. II:21).
- B. Student Experiment—Optical-Bench Method.
 1. Mount the concave mirror and screen on the optical bench. Hold the mirror so that rays from the sun fall directly upon it. Failing that, hold it so that rays from a candle held at the opposite end of the room fall upon it. Focus the image on the screen. To do this move the screen until the image is clear and sharply defined.
 2. Measure the distance of the image from the vertex of the mirror.

Observations

1. What is observed when parallel incident rays are reflected from the mirror?
2. Describe the image obtained when the object is at infinity.
3. What is the distance of the image from the vertex of the mirror?

Conclusions

1. What effect does a concave mirror have on light rays incident upon it?
2. Define: principal focus, focal length.

Questions

1. Why may a concave mirror be called a converging mirror?
2. Why did we use an infinitely distant object in the above experiment?

EXPERIMENT 7**To study the images produced by a concave mirror.**

(REF. SEC. II:22)

Apparatus

Optical bench, concave mirror of known focal length, candle, screen, finder.

Method

1. Place the candle at more than twice the focal length (f) from the mirror. Locate the image on the screen and state its characteristics.
2. Repeat the above for two or three other positions of the candle as it is gradually moved nearer to the principal focus of the mirror.
3. Place the candle between the principal focus and the mirror. Look into the mirror to see the image. Note its characteristics and locate its position by the method of parallax using the finder.

Observations

OBSERVATION NUMBER	POSITION OF OBJECT	POSITION OF IMAGE	CHARACTERISTICS OF IMAGE		
			SIZE	ATTITUDE	KIND
1.					
2.					
3.					

Conclusions

1. Where may an object be placed so that a real image of it is produced by a concave mirror?
2. Describe the changes in position and characteristics of the image as the object is gradually moved from infinity to the principal focus of a concave mirror.
3. Describe the position and characteristics of the image when the object is between the principal focus and the mirror.

Question

Make accurate scale diagrams to locate the images for the above positions of the object.

EXPERIMENT 8**To study the images produced by a convex mirror.**

(REF SEC. II:23)

EXPERIMENTS ON LIGHT

Apparatus

Optical bench, convex mirror, candle, finder.

Method

Using the candle at three different positions from the mirror, locate the image each time by the method of parallax, and state its characteristics.

Observations

OBSERVATION NUMBER	POSITION OF OBJECT	POSITION OF IMAGE	CHARACTERISTICS OF IMAGE		
			SIZE	ATTITUDE	KIND
1.					
2.					
3.					

Conclusions

1. What kind of image is produced by a convex mirror?
2. Describe the position and characteristics of the images produced by a convex mirror for all positions of the object.

Questions

1. How would you find the focal length of a convex mirror?
2. Why may such a mirror be called a diverging mirror?
3. Construct a geometric diagram to locate the image of an object produced by a convex mirror.

EXPERIMENT 9

To measure the refractive index of glass. (REF. SEC. II:28, 30)

Apparatus

Rectangular block of plate glass with one pair of opposite edges polished, sheet of paper, tack board, pins, geometrical instruments.

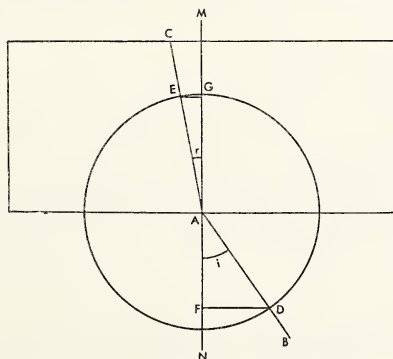


Fig. 13:4

Method

1. Lay the sheet of paper on the tack board. Place the glass block on the sheet of paper. Outline its position carefully.
2. Stick a pin A upright in the paper, near the centre of one edge of the glass and touching it.
3. Stick a second pin B upright in the paper about 2 in. from A so that a line joining the two meets the glass obliquely.
4. Look through the block, line up the images of A and B and insert pin C against the opposite edge of the glass block so that it and the images of A and B appear in a straight line. Mark the position of each pin.
5. Remove the block and pins and draw BA , and AC . Draw the normal MN at A . With centre A describe a circle to cut AB at D and AC at E . From D and E draw perpendiculars DF and EG to the normal MN .
6. Measure the distances DF and EG and calculate the value of $DF \div EG$. With a protractor measure the angles of incidence ($\angle BAF$) and of refraction ($\angle CAG$). Using a table of sines calculate $\sin \angle i \div \sin \angle r$.
7. Repeat for several other positions of the pins and arrange your results in the following observation table.

Observations

Obs. No.	DF	EG	DF/EG	$\angle i$	$\angle r$	$\sin \angle i / \sin \angle r$
1.						
2.						
3.						
4.						
	Average			Average		

Conclusion

Define: Index of Refraction.

Questions

1. Compare your experimental value with the theoretical value (table page 96). Calculate your percentage error.
2. Which way does light bend on entering obliquely a different medium of greater optical density? Why?

EXPERIMENT 10

To trace the path of light through a glass plate with parallel sides. (REF. SEC. II:31)

Apparatus

Same apparatus as in experiment 8.

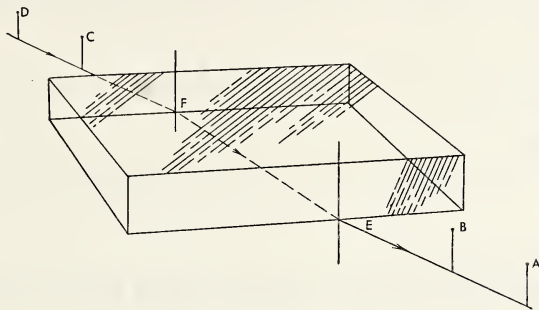


Fig. 13:5

Method

1. Lay the sheet of paper on the tack board. Place the glass block on the sheet of paper. Outline its position carefully.
2. Stick two pins *A* and *B* upright in the paper, about 2 in. apart, so that a line joining them (the incident ray) strikes the glass obliquely.
3. Look through the block, line up the images of *A* and *B* and insert pins *C* and *D* about 2 in. apart so that they and the images of *A* and *B* appear in a straight line. Mark the position of each pin.
4. Remove the block and pins. Join *AB* and produce it to meet the block at *E*. Join *CD* and produce it to meet the block at *F*. Join *EF*. On your diagram label the incident, refracted, and emergent rays.
5. Draw the normals at *E* and *F*. Measure the angle of incidence at *E*, and the angle of emergence at *F*.
6. Repeat the experiment for angles of incidence of different sizes.

Observations

1. In what direction relative to the normal does the light ray bend on entering the glass at *E* and on leaving it at *F*?
- 2.

	1.	2.	3.
Angle of incidence at <i>E</i> =			
Angle of emergence at <i>F</i> =			

Conclusions

1. How does the angle of incidence compare with the angle of emergence?

2. What relationship exists between the directions of the incident and emergent rays?
3. Describe the path of a light ray through a glass plate with parallel sides.

Explanation

Explain the observed bending of the light ray on entering and on leaving the glass.

Question

What factors affect the amount of lateral displacement of the emergent ray?

EXPERIMENT 11

To illustrate the apparent change in depth due to refraction of light at a plane surface. (REF. SEC. II:31)

Apparatus

Tall beaker, two pins, water.

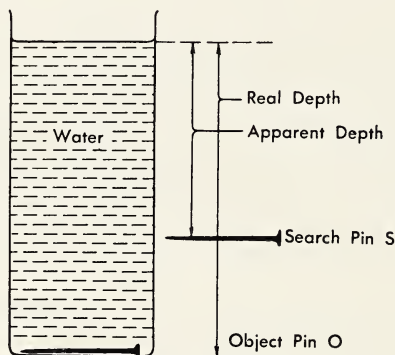


Fig. 13:6

Method

1. Place a pin at the bottom of the beaker and pour in water to a depth of about 15 cm. This pin is the object, *O*.
2. Hold the search pin, *S*, horizontally outside the beaker. View from directly above and adjust the position of the search pin until there is no parallax between it and the image of the object pin.
3. Determine the distance of the object pin, and of the search pin from the surface of the water, thus finding the real and apparent depths.
4. Repeat the experiment using different depths of water.
5. Tabulate your observations and determine the average value for $\text{real depth} \div \text{apparent depth}$.

Observations

OBSERVATION NUMBER	REAL DEPTH	APPARENT DEPTH	REAL DEPTH $\div$ APPARENT DEPTH
1.			
2.			
3.			
4.			

Conclusions

1. Construct a diagram to show the path of the light rays from the immersed object to an observer's eye.
2. Why is the apparent depth always less than the real depth?
3. Compare the value obtained by dividing the real depth by the apparent depth to the index of refraction of water (table, page 96).

Questions

1. In step 3 of the method, why must the measurements be made on the outside of the beaker?
2. If the water in the above experiment were replaced with an optically denser liquid, e.g., carbon tetrachloride, what effect would this have on the apparent position of the object? Why? Try the experiment.

EXPERIMENT 12

To show deviation produced by refraction through a prism.

(REF. SEC. II:32)

Apparatus

A 60° prism, sheet of paper, tack board, four pins, geometrical instruments.

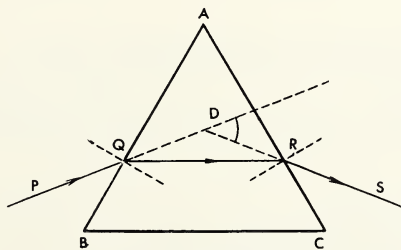


Fig. 13:7

Method

- A. Demonstration Experiment—Optical-Disc Method (Sec. II:32).
- B. Student Experiment—Pin Method.

1. Lay the sheet of paper on the tack board. Place the prism on the paper. Outline its position carefully. Label its vertices A , B and C .
2. Stick two pins P and Q upright in the paper about 2 in. apart so that Q is touching the prism, and a line joining them (the incident ray) strikes the surface of the prism, AB , obliquely.
3. Look through the prism on the side AC . Line up the images of P and Q and insert pins R and S about 2 in. apart with R touching the prism, so that they and the images of P and Q appear in a straight line. Mark the position of each pin.
4. Remove the prism and the pins. Join PQ , QR and RS . Label the incident, refracted and emergent rays.
5. Extend PQ and SR to meet at D . Measure the size of $\angle D$ (angle of deviation).
6. Construct the normals at Q and R . Measure the angle of incidence and the angle of emergence.
7. Repeat on separate diagrams for three other angles of incidence, including the special case where the angle of incidence is equal to the angle of emergence.

Observations

1. Which way does the light ray bend
 - (a) on entering the prism?
 - (b) on leaving the prism?
- 2.

OBS. No.	ANGLE OF INCIDENCE	ANGLE OF DEVIATION	ANGLE OF EMERGENCE
1.			
2.			
3.			
4.			

Conclusions

1. Describe the path of a light ray through a prism.
2. Describe how the angle of deviation varies as the angle of incidence is changed.
3. What is the relationship of the angle of incidence to the angle of emergence when the deviation is a minimum?

Questions

1. Draw a diagram showing a ray of light passing through the prism at the position of minimum deviation.
2. What factors affect the amount of deviation produced by a prism?

EXPERIMENT 13

To study the action of a convex and a concave lens, and to determine their focal lengths. (REF. SEC. II:35, 36)

Apparatus

Optical bench, convex lens, concave lens, candle, screen, finder.

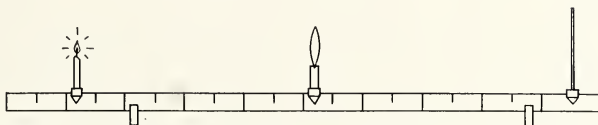


Fig. 13:8

Method

A. Demonstration Experiment—Optical-Disc Method (Sec. II:36).

B. Student Experiment—Optical-Bench Method.

1. Mount the convex lens and screen on the optical bench. Hold the lens so that rays of light from the sun, or from a distant candle, fall directly upon it. Focus the image on the screen.
2. Measure the distance of the image from the optical centre of the lens.
3. Repeat using the concave lens. In this case, in order to see the image, it is necessary to look into the lens toward the object. The position of the image can be determined by the method of parallax with the aid of the finder.

Observations

1. What is observed when parallel incident rays are refracted through (a) the convex lens, (b) the concave lens?
2. Describe the image obtained when the object is at infinity using (a) the convex lens (b) the concave lens.
3. What is the distance of the image from the optical centre of the lens?

Conclusions

1. What effect do (a) a convex lens, (b) a concave lens, have on light rays incident upon them?
2. Define: principal focus, focal length.

Questions

1. What other name may be given to (a) a convex lens, (b) a concave lens? Why?
2. Why did we use an infinitely distant object in the above experiment?

EXPERIMENT 14

To study the images produced by a convex lens.

(REF. SEC. II:37)

Apparatus

Optical bench, convex lens of known focal length, candle, screen, finder.

Method

1. Place the candle at more than twice the focal length (f) from the lens. Locate the image on the screen and state its characteristics.
2. Repeat the above for two or three other positions of the candle as it is gradually moved nearer to the principal focus of the lens.
3. Place the candle between the principal focus and the lens. Look into the lens to see the image. Note its characteristics and locate its position by the method of parallax using the finder.

Observations

OBSERVATION NUMBER	POSITION OF OBJECT	POSITION OF IMAGE	CHARACTERISTICS OF IMAGE		
			SIZE	ATTITUDE	KIND
1.					
2.					
3.					

Conclusions

1. Where may an object be placed so that a real image of it is produced by a convex lens?
2. Describe the changes in position and characteristics of the image as the object is gradually moved from infinity to the principal focus of a convex lens.
3. Describe the position and characteristics of the image when the object is between the principal focus and the lens.

Question

Make accurate scale diagrams to locate the images for the above positions of the object.

EXPERIMENT 15**To study the images produced by a concave lens.**

(REF. SEC. II:38)

Apparatus

Optical bench, concave lens, candle, finder.

Method

Using the candle at three different positions from the lens, locate the image each time by the method of parallax, and state its characteristics.

Observations

OBSERVATION NUMBER	POSITION OF OBJECT	POSITION OF IMAGE	CHARACTERISTICS OF IMAGE		
			SIZE	ATTITUDE	KIND
1.					
2.					
3.					

Conclusions

1. What kind of image is produced by a concave lens?
2. Describe the position and characteristics of the images produced by a concave lens for all positions of the object.

Questions

1. How would you find the focal length of a concave lens?
2. Why may such a lens be called a diverging lens?
3. Construct a geometric diagram to locate the image of an object produced by a concave lens.

EXPERIMENT 16

To study the dispersion of white light into the spectrum.

(REF. SEC. II:43(a))

Apparatus

Projection lantern, single slit, converging-lens, prism, white cardboard screen.

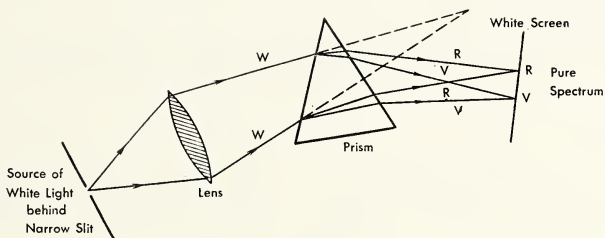


Fig. 13:9

Method

Direct a beam of light from the projection lantern on to the slit. Place the converging-lens in the light that diverges from the slit, and focus these rays on the screen at *A*. Place the prism in the path of the beam and note what happens to the light. Rotate the prism so that the emergent beam sweeps to and fro. Adjust the position of the prism until the emergent beam is as near as possible to *A*. The prism is now in the position of minimum deviation. Move the screen into the path of the beam and adjust its position until the light which falls on it is in clear focus.

Observations

1. What happened to the beam of light on passing through the prism?
2. Name the colours of the spectrum that you see.
3. Which coloured rays are deviated least, and which most, by the prism?

Explanation

1. Why is light deviated on passing through the prism?
2. Why are different colours deviated different amounts?
3. Which is deviated the least? Why? Which the most? Why?

Conclusions

1. What must white light consist of?
2. What is meant by dispersion of white light?

Questions

1. What would be observed if a sensitive heat detector were placed just beyond the red end of the spectrum? Why?
2. What would be observed if a fluorescent material (*e.g.*, anthracene), were placed just beyond the violet end of the spectrum? Why?

EXPERIMENT 17**To recombine the colours of the spectrum into white light.**

(REF. SEC. II:43(b))

Apparatus

As in experiment 16, second prism identical to one used there, second converging lens, Newton's colour disc, rotating-machine.

Method

1. With apparatus arranged as in experiment 16, place the second prism with its refracting edge in the opposite position to that of the first. Move the screen to catch the image. Note what is obtained.
2. With apparatus arranged as in experiment 16, place the second converging-lens in the spectrum. Move the lens until the image is brought to a focus on the screen. Again note what is observed.
3. Examine Newton's colour disc. Place on the rotator. Strongly illuminate it with white light from the projection lantern. Rapidly rotate it. Note the effect obtained.

Observations

Describe carefully what is observed in each part above. Include diagrams.

Conclusion

How may the colours of the spectrum be combined to form white light?

Explanation

1. Why did the reversed prisms and the converging-lens re-form white light?
2. Why did Newton's disc appear white when rapidly rotated?

Question

How could a concave mirror be used to recombine the colour of the spectrum?

EXPERIMENT 18

To study the spectra of a few common elements.

(REF. SEC. II:46)

Apparatus

Direct-vision spectroscope, Bunsen burner with monochromatic flame attachment, sodium, calcium and lithium salts; electrical discharge tubes containing neon, nitrogen and hydrogen, induction coil, source of direct current.

Method

1. Place a sample of the sodium salt in the attachment on the burner. Light the burner and heat the salt. Observe the flame through the spectroscope. Repeat for the other salts.
2. By means of the induction coil send a high-voltage discharge of electricity through the tube containing neon. Observe the discharge through the spectroscope. Repeat using the tubes containing the other gases.

Observations

Describe the spectra obtained and compare with those given in Fig. 11:6.

Conclusion

How is the spectrum of an element obtained?

Questions

1. What is meant by spectrum analysis?
2. What are some of its advantages?

EXPERIMENT 19

To study colour in natural objects (a) opaque (b) transparent.

(REF. SEC. II:47)

Apparatus

As in experiment 16, red, yellow and blue cardboard screens; red, yellow and blue glass filters.

Method

Produce a pure spectrum as outlined in experiment 16.

1. Replace the white screen by the coloured screens in turn. Note any change in the appearance of the spectrum each time.

2. With the white screen in place, insert each of the coloured filters in the path of the beam. Note any change in the appearance of the spectrum each time.
3. Repeat 2 using both the yellow and blue filters in the path of the light beam. Note the colour of the light obtained.
4. Repeat 2 using all three filters (red, yellow and blue) in the path of the beam. Note what is obtained.

Observations

Describe carefully all that is observed. Represent your observations by means of simple diagrams.

Explanation

Account for each of the observations.

Conclusion

What is the cause of colour in (a) opaque (b) transparent objects?

Questions

1. An object is viewed in white light and appears red. Why?
2. A blue filter is placed between the source of white light and the same object. What will be the appearance of the object? Why?

EXPERIMENT 20

To study the action of the astronomical refracting telescope.
(REF. SEC. II:55)

Apparatus

Optical bench, convex lenses of 20 cm. and 5 cm. focal lengths.

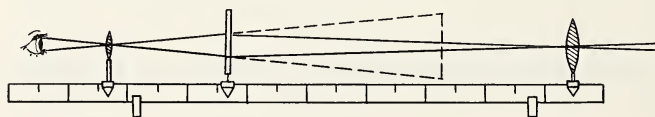
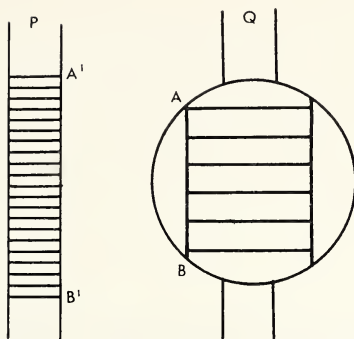


Fig. 13:10

Method

1. Place the two convex lenses on the optical bench so that the distance between them is equal to the sum of their focal lengths (25 cm.). Using the convex lens of shorter focal length as the eyepiece and the other as the objective, look through the lenses at distant objects.



- Construct two similar scales, *P* and *Q*, with divisions about 1 in. apart and place them near each other at the far end of the room. (Similar scales may be drawn on the blackboard if this is preferred.) Look through the telescope at the scale *Q* with one eye, and at the same time look at scale *P* with your other eye.

Have your partner mark the point on scale *P* which is level with the uppermost division of *Q* observed through the telescope. Repeat for the lowest division observed. Compare the number of complete divisions, *AB*, observed through the telescope with the number of corresponding scale divisions, *A'B'*, observed directly. Determine the magnifying power of the telescope.

Observations

- What is observed when distant objects are viewed through the telescope?
- How many complete scale divisions were observed
 - through the telescope? $AB =$
 - directly? $A'B' =$

Calculations

- Determine the magnifying power of the telescope from the above observations.
- Compare this value to that obtained by dividing the focal length of the objective by the focal length of the eyepiece.

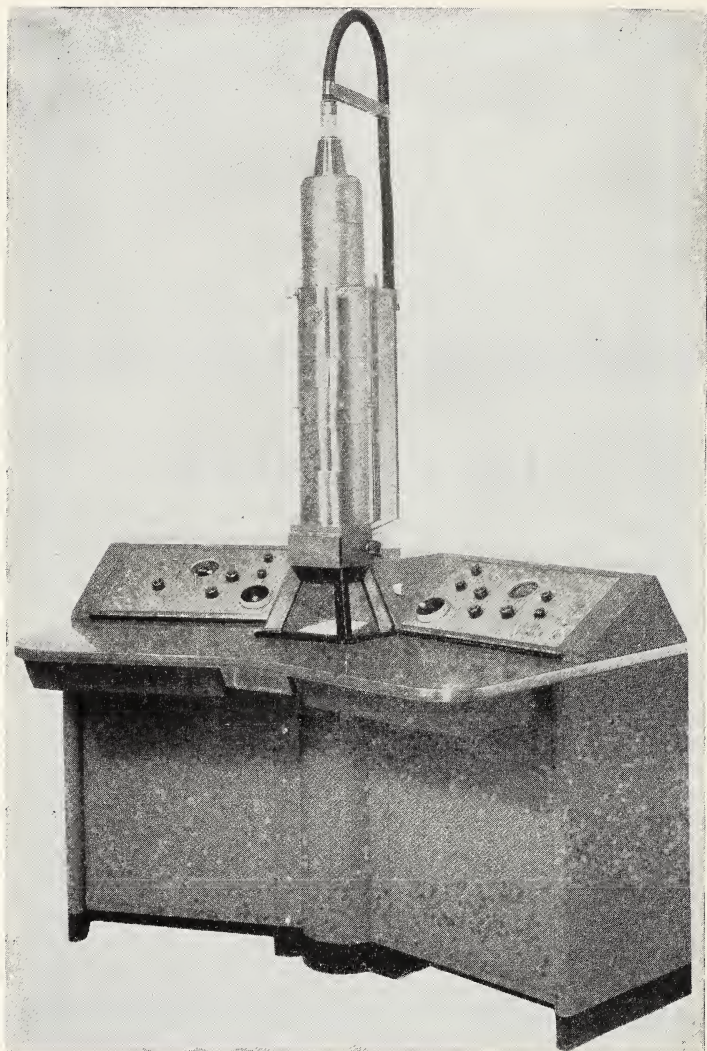
Conclusions

- What is the action of an astronomical telescope?
- What is the magnifying power of this telescope?

Questions

- By means of a diagram trace the paths of the light rays by which the observer sees the object through this telescope.
- What disadvantage has this telescope for viewing terrestrial objects? How could this disadvantage be overcome?

**MODERN DEVELOPMENTS
IN PHYSICS**



R.C.A. Victor Company, Ltd.

This Electron Microscope Permits Viewing of Particles Smaller Than One 10-Millionth of an Inch in Any Diameter. It Provides Magnification 50 Times Greater Than Heretofore Possible—So Great That a Human Hair Would Take on the Dimensions of a Subway Tunnel.

THIS TWENTIETH CENTURY

This has been called the age of Physics—a time when apparent luxuries have become commonplace necessities or gad-

gets of research have become ordinary articles of commerce. This century has seen the “horseless carriage”, originally a luxury, become a necessity for business and pleasure. The airplane in one generation has undergone an amazing development for peace and war. Electronics has given birth in turn to radio, radar and television.

In this chapter, a few modern developments are to be described. These are

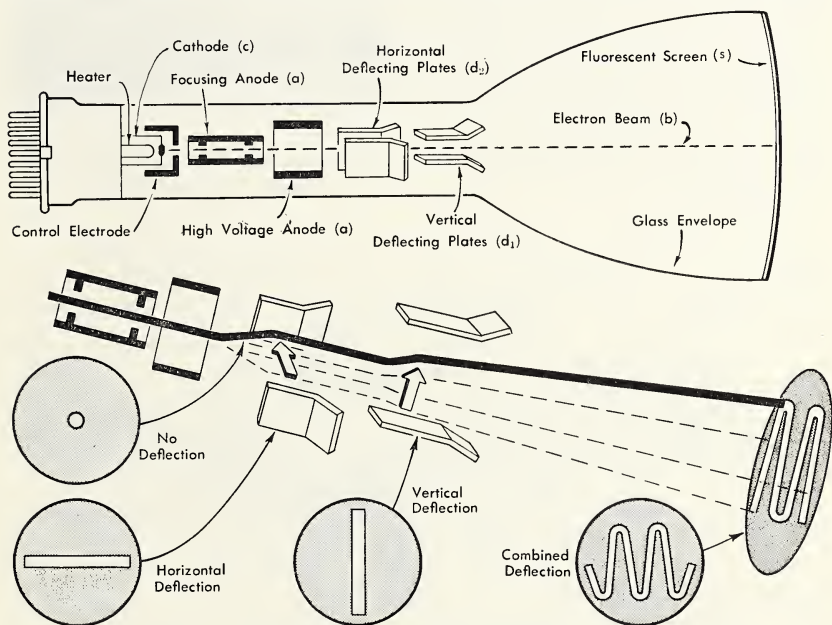
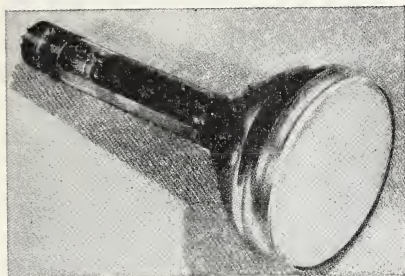


Fig. 14:1 The Cathode Ray Tube.

of the human eye produces the illusion of a continuous line of light on the screen. Thus, it is easy to see that if one voltage is used to make the beam sweep from side to side at a known uniform rate, another voltage applied to the ver-



Illus. Courtesy of Canadian Marconi Co.

A Picture Tube

tical deflection plates will make the spot write the autograph of the latter voltage on the screen, revealing in graphic form its frequency, wave form and other characteristics.

The commercial cathode-ray oscilloscope and tube is pictured in Fig. 14:2.

It combines in one circuit a cathode-ray tube, a sweep circuit, amplifiers, a power supply, all properly synchronized. This is probably the most widely used instrument in electronics, particularly in the testing and repair field. All kinds of sound—speech, noise, music—can be analyzed by the use of this instrument.

Television

In radio, electromagnetic waves modulated by the original sound-effects are transmitted through space. In television, a picture controlled by the light from the scene is transmitted at the same time as the sound. The feeble energy from such waves controls electric currents and magnetic fields in such a way as to reproduce the original sound and scene.

In the modern television camera, the essential component is an image orthicon, Fig. 14:3, not much bigger than a rolled-up magazine, but very complicated, sensitive and costly. It receives an optical image, I , of the scene on a thin metal coating, M , on the inside surface of the tube. Electrons are ejected from this screen in direct propor-

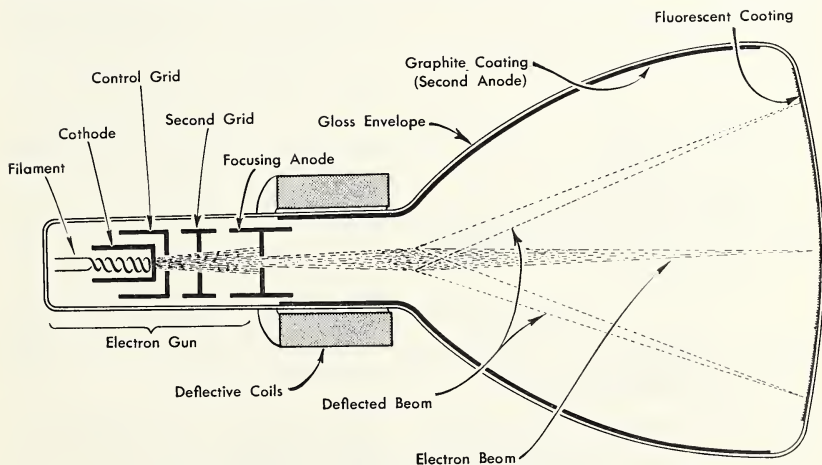
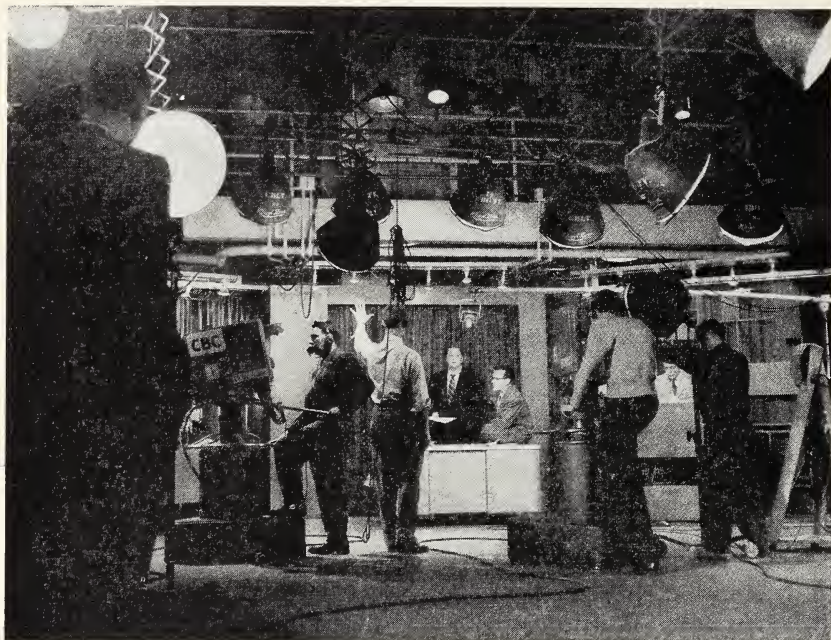


Fig. 14:4 The Kinescope (Picture Tube)



Canadian Broadcasting Corp.

Scene in Television Studio During a Broadcast.

tion to the brightness of the light that falls on it. These collect on the target screen, *T*, nearby and produce an elec-

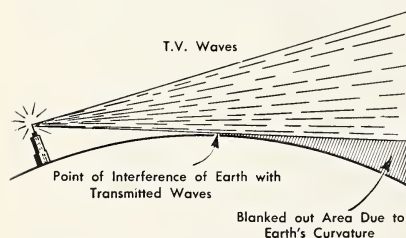


Fig. 14:5 The Effect of the Earth's Curvature on Television Waves.

tron image of the scene. This electron image is scanned by an electron beam, *B*, from the electron gun, *G*, in much

the same manner as you read a page in this book but much faster (covering 525 lines in $1/3$ sec.). The beam is controlled as in the cathode-ray tube. The speed of the electrons in the beam is so regulated that some of the electrons are repelled in a return beam whose intensity varies with the concentration of electrons on the target screen and, consequently, with the brightness of light from the scene. This return beam constitutes a weak current which is amplified, sent to a transmitter where it modulates ultra high frequency carrier waves that are broadcast much as are radio waves.

The main part of the receiving apparatus is another cathode-ray tube, called a kinescope (Fig. 14:4), that is

essentially the same as in the cathode-ray oscilloscope. The signal received by the antenna is amplified and then is



Bell Telephone Company of Canada

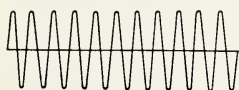
Fig. 14:6 A Relay Station.

applied to the tube in a manner that controls the intensity of the electron beam shot out by its electron gun. The

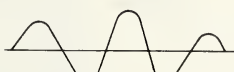
motion of this beam is synchronized with the scanning of the image orthicon. Since the intensity of the beam and hence the brightness of the spot on the screen varies with the signal received, the beam produces a reproduction of the original scene 30 times per second. The illusion of a continuous picture is explained by the rapidity of scanning and our persistence of vision.

Television waves travel in a straight path. Each transmitter's coverage is an area with a radius of about 130 miles on account of the earth's curvature (Fig. 14:5). Obviously, this presents a problem in telecasting events of national importance from coast to coast. To overcome the difficulty a series of relay stations (Fig. 14:6) has been developed which is used both for television and telephone conversations using short waves called microwaves to carry the energy. Each frequency carries several messages. Waves of this kind can be focused and aimed at the next station so that little energy is lost.

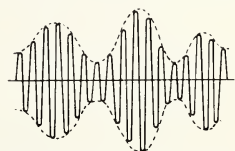
The sound system of television is of the type called frequency modulation (F.M.) unlike that of ordinary radio which is amplitude modulation (A.M.). In the latter, the signal modulates (alters



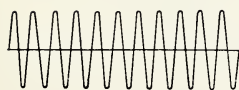
(i) Carrier Frequency



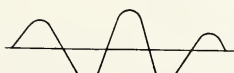
(ii) Sound Pattern



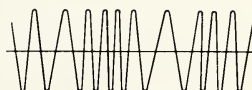
(iii) Amplitude Modulated Carrier



(i) Carrier Frequency



(ii) Sound Pattern



(iii) Frequency Modulated Carrier

Fig. 14:7 (a) Amplitude Modulation.
(b) Frequency Modulation.

the form of) the amplitude of the carrier wave as in Fig. 14:7a. Such a wave is affected by all kinds of outside electromagnetic disturbances (static). In the former, the signal modulates the frequency of the carrier wave as in Fig. 14:7b. Such a wave is free from static.

In one method for colour television, the camera has three separate orthicons operating behind red, green and blue filters respectively and giving rise to three different signals. In the receiver each signal puts its own corresponding component of the picture tube into operation. The end of the picture tube is dotted with "phosphors" that will glow red, green or blue, when properly stimulated. When all three phosphors are made to glow by their respective electron beams, the original scene is reproduced in full colour.

Radar

The word radar is a contraction of the words Radio Detection And Ranging which gives a good idea of what it means. Man has known for centuries that echoes are useful in detecting distant obstacles and determining their position. We know that the bat uses the echo of

his high-pitched squeak to enable him to avoid objects as he flies back and forth in the dark. Mariners have used the echo of the ship's whistle to locate shorelines and icebergs. High frequency radio waves (300 to 3000 megacycles per second) are used for the same purpose in radar. At these frequencies they resemble light waves and can be reflected, refracted and focused. Like light they travel in straight lines. The radar principle, first used in 1924 in exploring the upper regions of the earth's atmosphere was adapted by Sir Robert Watson Watt for the location of aircraft, ships and shorelines in World War II. It was this device which enabled those few valiant defenders of the British Isles (and of the freedom of the world) during the Battle of Britain to earn those remarkable words of Sir Winston Churchill when he said, "Never . . . was so much owed by so many to so few".

The distance from an observer to an object may be computed if we know the time required for sound to travel to it and for the echo to return. Similarly, the distance of an aircraft may be determined by sending out a pulse of high-frequency radio waves, P , Fig. 14:8a, from the transmitter, T , and detecting the reflected

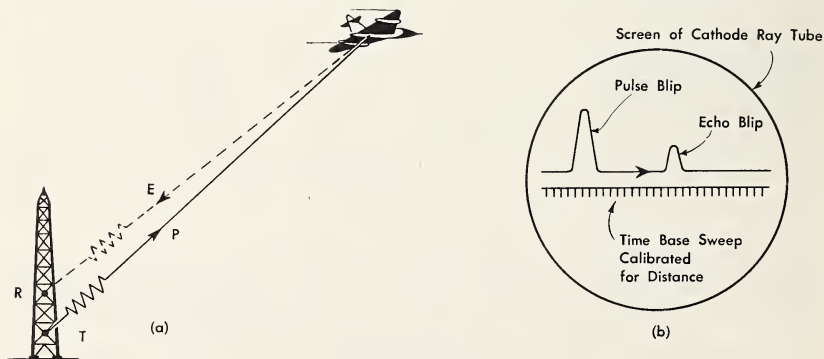


Fig. 14:8 (a) Using Radar in Aircraft Detection.
(b) View of Screen of Receiver.

impulse, E , by a receiver, R . If the time interval required is determined and the velocity of radio waves (186,000 mi. per sec.) is known, the distance may be determined.

The receiver contains a cathode-ray tube in which the spot is made to traverse the screen at a constant known speed. The outgoing and echo signals generate voltages which are applied to the vertical plates and produce upward jolts or "blips" on the trace (Fig. 14:8b). The distance between these blips enables the operator to calculate the time interval.

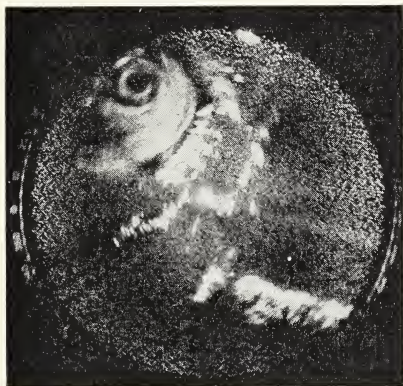
To specify the position of an aircraft we must know the bearing and the elevation. The former is detected by comparing the strength of the echo signals from two sending aerials set at right angles. The elevation can be determined

Radar has numerous peace-time applications. It is used to follow the flight of aircraft flying over lonely or thinly-populated areas like the far north. Aerial and water transport employ it at night and in fog to avoid striking obstacles. Highway traffic authorities find it valuable in tracking down speeding drivers.

The Electron Microscope

It can be shown that the ability of a microscope to reveal the fine detail of an object (the resolving power) is limited by the wave-length of the light used. Consequently, the practical upper limit of magnifying power that can be obtained with optical microscopes—using visible light—is about 2000 diameters. Now it is known that an electron stream behaves in a manner very similar to a light beam but with an effective wave-length some 10,000 times smaller, permitting examination of bacteria, viruses and very large molecules.

Accordingly scientists, especially Dr. F. Burton and his associates at the University of Toronto in the 1930's explored the possibility of using electrons in microscopy. As a result of their researches the electron microscope, shown diagrammatically in Fig. 14:9, was developed. The electrons are produced by a heated cathode and are accelerated under a potential of some 50,000 volts applied to an anode with a central hole from which they emerge in a stream of swiftly moving electrons. The electron stream is converged and focused by magnetic and electric fields much as light is by glass lenses in an optical microscope. These "magnetic lenses" consist of short solenoids entirely encased in a steel shield except for a narrow gap in the centre through which the electrons pass and where they become deflected. The arrangement of lenses is similar to that in the optical microscope but the object to be studied is very much thinner ($1/100$,-

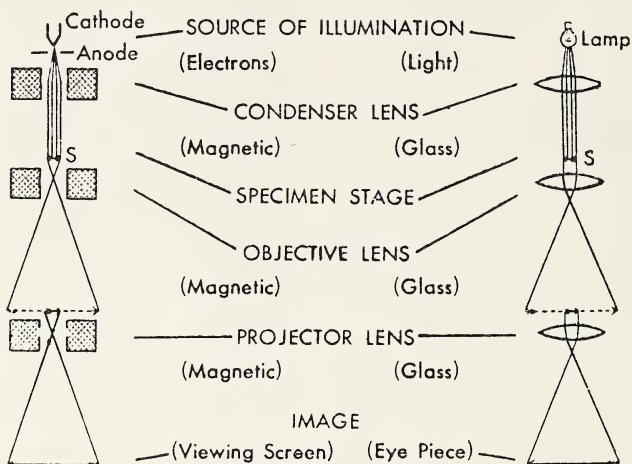


Canadian Aviation

This Radar Screen Has Picked Up a Typhoon.

with the aid of two aerials each above the other. To recognize friendly aircraft the radar pulse triggers a special transmitter and consequently the return pulse will be given a special mark which is distinguished on the cathode-ray tube.

ELECTRON MICROSCOPE OPTICAL MICROSCOPE



R.C.A. Victor Company Ltd.

Fig. 14:9 A Comparison of Electron and Optical Microscopes.

000 cm. thick). The instrument must be evacuated to prevent deflection of the electron stream as it collides with air molecules. The varying penetrations of the electrons through the object produce a sort of shadow picture on the fluorescent viewing screen or photographic film. Magnifications of up to 100,000 diameters have been obtained.

The electron microscope has proved to be a very valuable tool in the hands of the research worker. It has revealed new facts about particle shapes and sizes which affect such processes as the covering power of paint pigments, the wearing quality of rubber tires and the operation of chemical catalysts. It has

COMPARISON OF SOME MAGNIFIERS

<i>Object</i>	<i>Diameter (Microns)</i>	<i>Magnification (Diameters)</i>	<i>Instrument</i>
Fine Machine Work	25-100	8	Hand lens
Pond Life Fungi	10-25	20	Low power optical
Bacteria	1-2	200	Medium power optical
Structure of Bacteria	0.25	1000.	High power optical
Large Virus	0.10	2000.	Special optical microscope or electron microscope
Colloidal Particles	0.05	4000.	Electron microscope
Small Viruses	0.01	20,000	Electron microscope
Large Molecules	0.002	100,000	Electron microscope

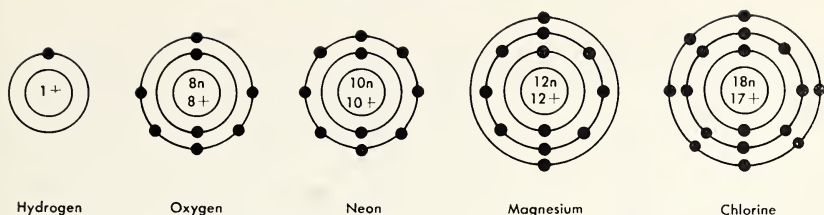


Fig. 14:10 Diagrams of Several Atoms—Electrons (•), Protons (+), Neutrons (n).

provided new information in such fields as metallurgy, chemistry, ceramics, crystallography, plastics, textiles, biology and medicine.

NUCLEAR PHYSICS

Our knowledge of the structure of matter has made great progress since the turn of the century. Experimental work beyond the scope of this text has led to a concept of the atom far different from that held until 1897. Until that time the atom was thought to be the smallest particle of matter. Since then our concept of the structure of the atom has been constantly changing. For our purposes it is convenient to think of the atom as follows:

1. It may be pictured as a miniature solar system with a central relatively large mass, called the **nucleus** corresponding to our sun, and a number of smaller objects, called **electrons** travelling in their orbits about the nucleus much as the planets move around the sun.
2. The nucleus is composed of two kinds of particles:
 - (a) **Protons**—which are positively charged and are considered to have unit mass.
 - (b) **Neutrons**—which have no electric charge and have the same mass as the proton.
3. The electrons are negatively charged and are approximately $\frac{1}{1840}$ as heavy as a proton.

4. Atoms are normally neutral in charge. Therefore we may conclude that in each atom there must be as many electrons moving around the nucleus as there are protons within the nucleus.
5. There are over one hundred different kinds of atoms known at the present time. Scientists believe that even more will be identified in the near future. The atoms of different elements differ from each other in the numbers of protons and neutrons contained in the nucleus and in the number and arrangements of electrons in their orbits. Some typical diagrams of atoms are shown in Fig. 14:10.

This knowledge of the atom came about by a process of gradual evolution. First was the discovery of the electron by Sir J. J. Thomson as a result of his work on cathode rays. Later, studies on radioactivity contributed much to knowledge about the nucleus of the atom.

Radioactivity

In 1896 the French physicist Becquerel noticed that salts of uranium affected a neighbouring photographic plate. He concluded that these salts must be emitting rays or particles spontaneously generated by the salts themselves. This phenomenon was called radioactivity and was extensively investigated by Pierre and Marie Curie. Using pitch-blende, a natural ore rich in uranium compounds, they succeeded, after a long series of

repeated crystallizations, in isolating two new elements, polonium and radium, which were more radioactive than

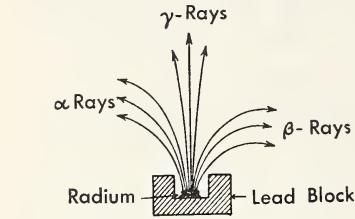


Fig. 14:11 Radium Emanations.

uranium. Later work by the Curies and others has revealed, indeed, that quite a number of the heavier elements are radioactive.

In 1903 Rutherford undertook a careful examination of the nature of the radiation from radioactive substances. He showed, by applying a magnetic field, Fig. 14:11, that the radiation could be resolved into three distinct

groups of rays which he called alpha (α), beta (β), and gamma (γ) rays, the α -rays being deflected in one direction, the β -rays in the opposite direction, while the γ -rays do not undergo deflection. Further experiments showed that the α -rays were positively charged helium nuclei, the β -rays, negative electrons, and that the γ -rays were highly penetrating, short wave-length, energy waves. Rutherford came to the conclusion that the nuclei of radioactive substances are spontaneously disintegrating into the above rays and changing into new elements as they do so. Fig. 14:12 shows the sequence of changes through which uranium goes as it gradually changes into lead.

The Structure of the Atom

Rutherford found that α -particles would pass through a thin sheet of metal, and concluded that there was considerable empty space in the atom. His concept of the atom was a miniature solar system consisting of electrons

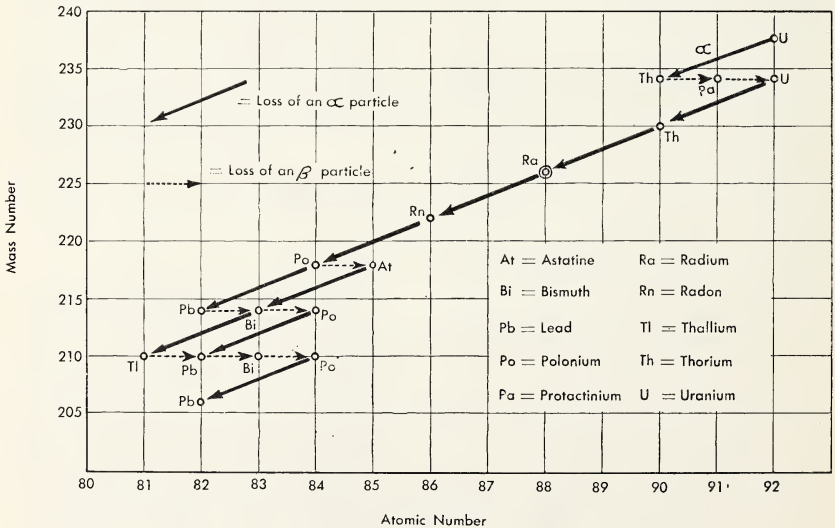


Fig. 14:12 The Uranium Disintegration Series.

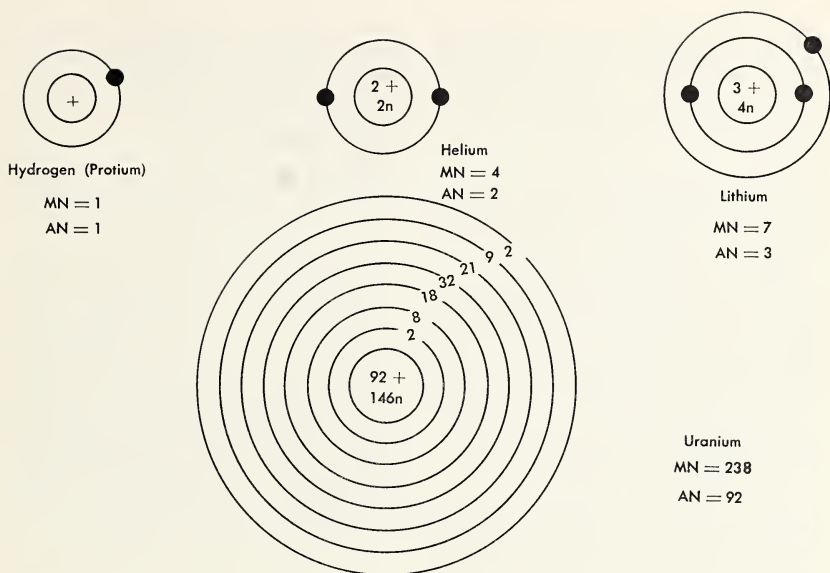


Fig. 14:13 Structure of Some Atoms. (MN = Mass Number; AN = Atomic Number)

revolving about a positively charged nucleus. Later, while at McGill University, he was able to isolate the hydrogen ion or proton. Moseley's experiments, in England, with X-ray phenomena on various elements, indicated the presence of these protons in every nucleus and a different number in the nuclei of different elements. The number of protons in the nucleus of the atom is the **atomic number** or **nuclear charge**. Since the atom is electrically neutral, the number of electrons revolving about the nucleus must equal the number of protons in the nucleus, and hence must also equal the atomic number.

Rutherford's atom served until the

discovery by Sir James Chadwick in 1932 of the neutron. This particle (which was earlier predicted by Rutherford) has the same mass as the proton but possesses no charge. It is now believed that atomic nuclei are built up of protons and neutrons. The sum of the protons plus the neutrons make up what is called the **mass number** of the atom. In general the number of neutrons in the nucleus is equal to the mass number minus the nuclear charge or atomic number. For example, the helium nucleus which has an atomic number of 2 and a mass number of 4 must contain 2 protons and 2 neutrons.

Finally, to complete the picture of the

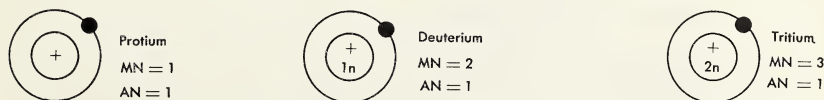


Fig. 14:14 Isotopes of Hydrogen.

atom, Niels Bohr postulated that the electrons revolved in various orbits, or energy levels, about the nucleus. The Bohr Concept for a number of typical atoms is shown in Fig. 14:13.

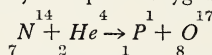
Isotopes

About this time, it was discovered by Rutherford and Aston in England that although all atoms of an element have the same chemical properties some differed from others in mass. Such forms of any element are called *isotopes*. They postulated that all the isotopes of any one element must have the same number of protons and electrons and hence the same atomic number, but must differ in the number of neutrons in the nucleus and hence must differ in mass number. Most elements consist of a number of isotopes. For example, hydrogen is thought to consist of a mixture of three isotopes (Fig. 14:14). Protium is the commonest isotope of hydrogen. Deuterium is the isotope of hydrogen that is found in heavy water. The nucleus of deuterium, called a deuteron, is

much used in experimental work in nuclear physics. Tritium is a very rare isotope of hydrogen that is of importance in the hydrogen bomb.

Artificial Transmutation

The above interpretation of natural radioactivity suggested to Rutherford the possibility of bringing about the disintegration of other nuclei. This was accomplished by Rutherford in 1919 while at McGill by using α -particles from a radioactive source to bombard nitrogen atoms. As a result of the collisions he found that some of the nitrogen atoms had a proton ejected from them, the α -particle remaining with the disrupted nucleus. These atoms therefore had a net increase of 1 proton and 2 neutrons and hence became oxygen atoms (actually a heavy isotope of oxygen):



Thus was achieved the first artificial transmutation of the elements—the old alchemists' dream becoming a reality!

Rutherford next considered the use of

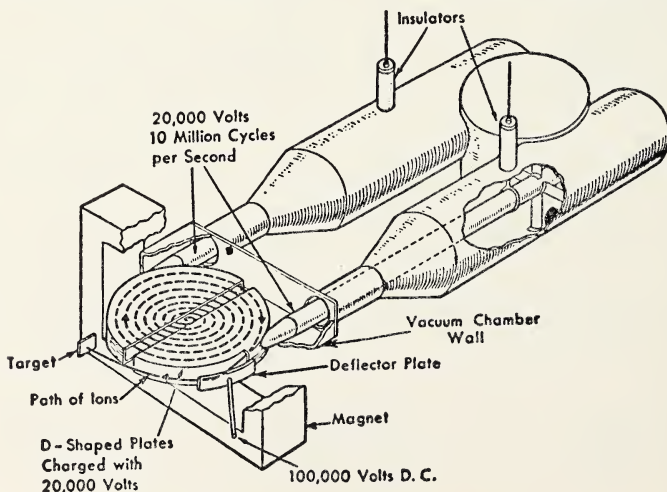
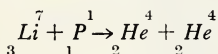


Fig. 14:15 Diagram of a Cyclotron.

artificially energized particles as a more effective means of bringing about nuclear changes, using protons accelerated under a potential difference of about half a million volts. These high-speed protons were directed on to a lithium target, some of the atoms of which were split up to form helium atoms:



Other light elements were disintegrated by this means, but it was realized that even more energetic particles were required to attack the nuclei of heavier elements on account of the large forces of repulsion between the bombarding particles and the larger nuclear positive charge. Particles having the necessary energy for this purpose can be produced by means of the cyclotron (Fig. 14:15). This latter machine, first invented by the American physicists Lawrence and Livingston in 1930, is capable of rapidly accelerating charged particles such as protons and deuterons.

Nuclear Fission

The discovery of the neutron provided physicists with a most effective projectile with which to bombard atomic nuclei

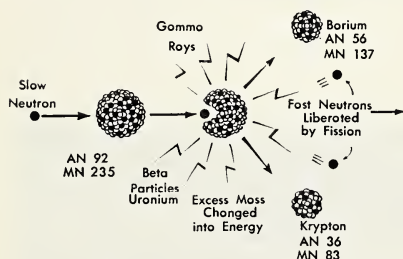


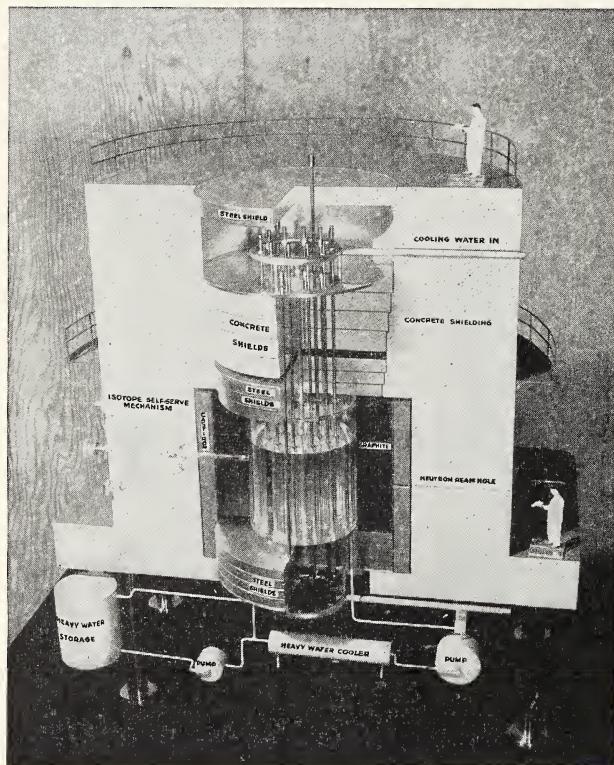
Fig. 14:16 Nuclear Fission.

because, having no charge, a neutron can approach the positive nucleus of an atom without any repulsive force. A

common way of producing neutrons for this purpose is to bombard beryllium metal by a beam of fast-moving deuterons from a cyclotron—neutrons being knocked out of the beryllium nuclei. It was while bombarding uranium 235 (a light unstable isotope of uranium) with neutrons in 1939, that Hahn and Strassmann discovered an entirely new form of nuclear transformation, Nuclear Fission, in which the uranium nucleus was split into two nearly equal parts with the release of a large amount of energy (Fig. 14:16). Another interesting feature of the fission of uranium is that during the process further neutrons are emitted in relatively larger numbers than those absorbed. Thus from each uranium nucleus undergoing fission two or more neutrons are released. The neutrons so released can then cause fission in other uranium nuclei and so on causing a chain reaction. If allowed to proceed in this way, provided that there is a suitable amount of fissionable matter present, the whole of the material is transformed in a very short time, with the release of vast quantities of energy. This is the principle of the atomic bomb. It has been proven that the combined mass of the products is a little less than the mass of original material. Dr. Albert Einstein as early as 1905 using his famous equation, $E = MC^2$, predicted what we now know—that the mass lost becomes transformed into the energy of the explosion. E represents the energy, M the loss in mass and C , a constant quantity equal to the speed of light (Sec. II:6). Thus we can see that a small amount of mass is transformed into a tremendous amount of energy.

Nuclear Reactors

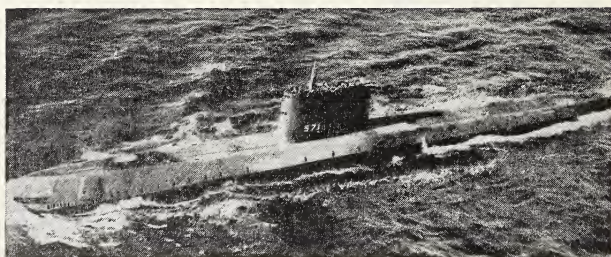
If the neutrons from the fission of U 235 are absorbed or slowed down as they are produced, the chain reaction can be controlled and the energy re-



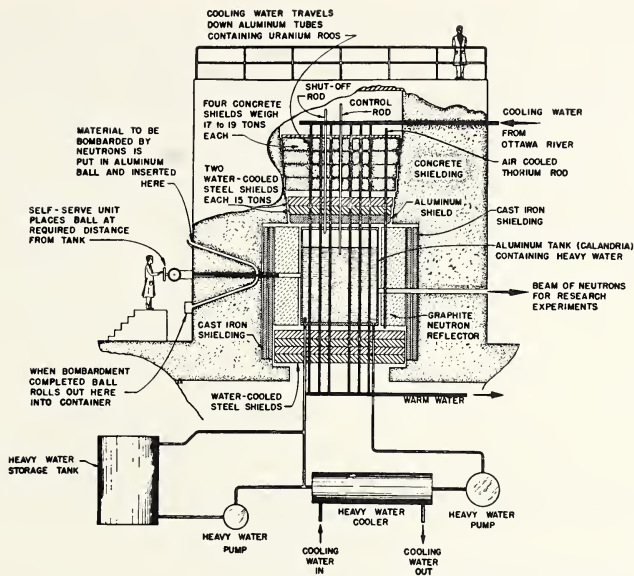
Model of N.R.X. Re-
actor, Chalk River,
Ontario.

Atomic Energy of Canada Ltd.

U.S.S. Nautilus. The
First Atomic Powered
Submarine.



Star Newspaper Service



Atomic Energy of Canada Ltd.

Diagram of N.R.X. Reactor, Chalk River, Ontario.

leased put to useful purposes. Graphite and certain other light substances which possess the property of absorbing neutrons, are used to control the rate of neutron emission in atomic fission and are called moderators. The assembly of uranium (or other fissile material) and graphite (in the form of blocks or rods) is known as an atomic pile or nuclear reactor (page 170), the rate of energy release being controlled by adjusting the length of the graphite rods inserted in the pile. The energy released is transformed into heat which is used for various purposes. Energy is variously measured. The engineer may express it as B.T.U. per pound. The nuclear physicist may express it in electron volts per atom. One B.T.U. equals 665×10^{13} million electron volts. It is estimated that, if coal gives 13,600 B.T.U. per pound, this

is 4 electron volts per atom of carbon. By comparison one atom of uranium produces 200 million electron volts. This means that one atom of uranium produces 50 million times as much energy as one atom of carbon or if you have equal masses of coal and uranium the amount of energy released from the uranium is 3 million times as great. There is little wonder, therefore, that the search for uranium goes on at a feverish pace.

Atomic Fusion

In 1951 when man was congratulating himself on his conquest of the atom through turning fission to his advantage, a new and still more exciting process was evolved by Dr. Edward Teller in the United States. Hans Bethe's theory of the origin of the sun's continuous heat by the union of four atoms of

hydrogen to form an atom of helium accompanied by the conversion of a small amount of mass into energy. Dr. Teller employed this process using the isotopes of hydrogen—protium, deuterium and tritium—resulting in the production of a source of energy far greater than ever realized before. The hydrogen bomb was created which was fantastically devastating. A source of energy was born that was so amazing that it may well be

the source of energy of the future.

Space does not permit dealing at any length with the many and varied uses of atomic energy. Suffice it to say that biological, medical, agricultural and industrial research are greatly benefiting from the developments made in this field as are some users of industrial and domestic power. The possibilities are as yet beyond man's fondest dreams.

APPENDIX A: FORMULAE

1. Density

$$D = \frac{m}{V}$$

D is density;

m is mass;

V is volume of mass.

2. Specific Gravity of a Solid or Liquid

$$\text{S.G.} = \frac{D_s}{D_w}$$

S.G. is specific gravity of substance;

D_s is density of substance;

D_w is density of water.

3. Specific Gravity of a Solid denser than water by Archimedes' Principle

$$\text{S.G.} = \frac{\text{weight in air}}{\text{buoyant force of water}}$$

4. Specific Gravity of a Substance less dense than water by Archimedes' Principle

$$\text{S.G.} = \frac{W_1}{W_2 - W_3}$$

W_1 is weight of substance in air;

W_2 is weight of substance in air and sinker in water;

W_3 is weight of substance and sinker in water.

5. Specific Gravity of a Liquid

(a) Bottle Method

$$\text{S.G.} = \frac{W_L}{W_w}$$

W_L is weight of liquid;

W_w is weight of water.

(b) Loss-of-Weight Method by Archimedes' Principle

$$\text{S.G.} = \frac{F_L}{F_w}$$

F_L is buoyant force of liquid;

F_w is buoyant force of water.

(c) Hydrometer Method

$$\text{S.G.} = \frac{D_w}{D_L}$$

D_w is depth rod sinks in water;

D_L is depth rod sinks in liquid.

6. Work

$$W = Fs$$

W is work;

F is force;

s is distance.

7. Power

$$P = \frac{Fs}{t}$$

P is power;

Fs is work;

t is time.

8. Efficiency

$$\text{Efficiency} = \frac{\text{Useful work}}{\text{Total work}} \text{ or } \frac{\text{Output}}{\text{Input}}$$

9. Centigrade and Fahrenheit Scales

$$C = 5/9 (F - 32)$$

C and F represent Centigrade and Fahrenheit thermometer readings.

10. Images in Mirrors and Lenses

(a) Magnification Formula

$$\frac{H_i}{H_o} = \frac{D_i}{D_o}$$

H_i is height or size of image;

H_o is size of object;

D_i is distance of image;

D_o is distance of object.

(b) Distance Formula

$$\frac{1}{D_o} + \frac{1}{D_i} = \frac{1}{f}$$

D_o is distance of object;

D_i is distance of image;

f is focal length.

11. Index of Refraction

$$(a) \quad \mu = \frac{V_a}{V_m}$$

μ is index of refraction of a medium;

V_a is velocity of light in air;

V_m is velocity of light in the medium.

$$(b) \quad \mu = \frac{\sin \angle i}{\sin \angle r}$$

$\angle i$ is angle of incidence;

$\angle r$ is angle of refraction.

12. Power of Lenses

$$P = \frac{100}{f}$$

P is power in dioptries;

f is focal length in cm.

13. Wave Formula

$$C = f \lambda$$

C is velocity of light;

f is frequency;

λ is wave-length.

14. Simple Magnifier

$$\text{Magnifying Power} = \frac{25 \text{ cm.}}{f} \text{ or } \frac{10 \text{ in.}}{f}$$

f is focal length of lens in units indicated.

15. Compound Microscope

$$\text{Magnifying Power} = \frac{25L}{f_e f_o}$$

L is length of tube in centimetres;

f_e is focal length of eyepiece in centimetres;

f_o is focal length of objective in centimetres.

16. Refracting Telescope

$$\text{Magnifying Power} = \frac{F}{f}$$

F is focal length of objective;

f is focal length of eyepiece.

17. Illumination

$$E = \frac{I}{d^2}$$

E is illumination;

I is intensity;

d is distance from source to illuminated surface.

18. Photometer

$$\frac{I_1}{d_1^2} = \frac{I_2}{d_2^2}$$

I_1 is the standard intensity;

d_1 is the distance of screen from standard lamp;

I_2 is the unknown intensity;

d_2 is the distance of screen from unknown lamp.

APPENDIX B: TABLES

Table I: Useful Values and Relationships.

12 in.	= 1 ft.	1 ft. ³ of water weighs	62.4 lb.
3 ft.	= 1 yd.	1 litre of air (S.T.P.) weighs	1.29 gm.
5280 ft.	= 1 mi.	1 horsepower	= 746 watts
1760 yd.	= 1 mi.	1 kilowatt	= 1.34 horsepower
144 in. ²	= 1 ft. ²	1 B.T.U.	= 252 calories
9 ft. ²	= 1 yd. ²	1 calorie	= 4.2 joules
1728 in. ³	= 1 ft. ³	velocity of light	= 186,000 miles per sec.
27 ft. ³	= 1 yd. ³		= 300 × 10 ⁶ m. per sec.
231 in. ³	= 1 gal.	1 Ångstrom	= 10 ⁻⁸ cm.
60 mi./hr.	= 88 ft./sec.	circumference of a circle	= 2πr
7000 grains	= 1 lb. avoirdupois	area of a circle	= πr ²
16 oz.	= 1 lb. "	surface of a sphere	= 4πr ²
2000 lb.	= 1 short ton	volume of a sphere	= $\frac{4}{3}\pi r^3$

Table 2: Metric-English Equivalents.

1 in.	= 2.5400 cm.	1 cm. ²	= 0.1550 in. ²
1 ft.	= 30.480 cm.	1 in. ³	= 16.3872 cm. ³
1 yd.	= 91.440 cm.	1 cm. ³	= 0.0610 in. ³
1 mi.	= 1609.4 m.	1 grain	= 0.06480 gm.
1 mi.	= 1.6094 km.	1 oz.	= 28.3495 gm.
1 mm.	= 0.03937 in.	1 lb.	= 453.592 gm.
1 cm.	= 0.3937 in.	1 lb.	= 0.4536 kgm.
1 m.	= 39.37 in.	1 gm.	= 15.4324 grains
1 m.	= 3.2808 ft.	1 gm.	= 0.03527 oz.
1 m.	= 1.0936 yd.	1 gm.	= 0.002205 lb.
1 km.	= 0.621 miles	1 kgm.	= 2.2046 lb.
1 in. ²	= 6.4516 cm. ²	1 litre	= 0.880 Imp. quarts

Table 3: Specific Gravity of Solids.

Aluminum	2.7	Diamond	3.53
Bakelite	1.25-2.09	Glass, crown	2.5
Brass	8.4-8.7	Gold	19.3
Bronze	8.8	Granite	2.65
Carbon	1.9-3.5	Graphite	2.25
Coal, anthracite	1.4-1.8	Human Body	1.07
Coal, bituminous	1.2-1.5	Ice	0.917
Copper	8.9	Iron, cast	7.1-7.7
Cork	0.24	Iron, steel	7.6-7.8

Table 3—continued

Iron, wrought	7.8-7.9	Pine	0.37-0.64
Lead	11.4	Platinum	21.5
Limestone	2.7	Porcelain	2.38
Magnesium	1.74	Silver	10.5
Maple	0.51-0.75	Sulphur	2.0
Marble	2.6-2.8	Tin	7.3
Oak	0.60-0.98	Tungsten	19.3
Paraffin	0.87-0.91	Zinc	7.1

Table 4: Specific Gravity of Liquids.

(Room Temperature)

Alcohol, ethyl	0.789	Hydrochloric acid	1.20
Alcohol, methyl	0.793	Kerosene	0.82
Carbon disulphide	1.29	Mercury	13.56
Carbon tetrachloride	1.60	Milk	1.029
Chloroform	1.50	Nitric acid, 68%	1.42
Ether	0.74	Sulphuric acid	1.84
Gasoline	0.66-0.69	Water, sea	1.025
Glycerine	1.26		

Table 5: Specific Gravity of Gases.

(Air Standard, at 0° and 760 mm. of mercury 1.29 gm./l)

Acetylene	0.907	Helium	0.138
Air	1.000	Hydrogen	0.0695
Ammonia	0.596	Hydrogen chloride	1.268
Argon	1.380	Methane	0.554
Carbon dioxide	1.529	Neon	0.696
Carbon monoxide	0.967	Nitrogen	0.967
Chlorine	2.486	Oxygen	1.105
Ethane	1.049	Sulphur dioxide	2.264

Table 6: Density of Water at Various Temperatures.

°C	gm./cm. ³	°C	gm./cm. ³	°C	gm./cm. ³
0	0.99987	15	0.99913	60	0.98324
1	0.99993	20	0.99823	65	0.98059
2	0.99997	25	0.99707	70	0.97781
3	0.99999	30	0.99567	75	0.97489
4	1.00000	35	0.99406	80	0.97183
5	0.99999	40	0.99224	85	0.96865
6	0.99997	45	0.99025	90	0.96534
8	0.99988	50	0.98807	95	0.96192
10	0.99973	55	0.98573	100	0.95838

Table 7: Velocity of Sound in Various Media.
(Approximate)

Material	ft./sec.	Material	ft./sec.
Air	1,087	Hydrogen	4,165
Alcohol	3,890	Iron	16,500
Aluminum	16,740	Maple, along grain	13,470
Brass	11,480	Pine, along grain	10,900
Copper	11,670	Steel	16,500
Glass	16,500	Water	4,794

Table 8: Natural Sines and Tangents.

Angle	Sine	Tangent	Angle	Sine	Tangent	Angle	Sine	Tangent
0	0.000	0.000	31	0.515	0.601	62	0.883	1.881
1	0.017	0.017	32	0.530	0.625	63	0.891	1.963
2	0.035	0.035	33	0.545	0.649	64	0.899	2.050
3	0.052	0.052	34	0.559	0.675	65	0.906	2.145
4	0.070	0.070	35	0.574	0.700	66	0.914	2.246
5	0.087	0.087	36	0.588	0.727	67	0.921	2.356
6	0.105	0.105	37	0.602	0.754	68	0.927	2.475
7	0.122	0.123	38	0.616	0.781	69	0.934	2.605
8	0.139	0.141	39	0.629	0.810	70	0.940	2.747
9	0.156	0.158	40	0.643	0.839	71	0.946	2.904
10	0.174	0.176	41	0.656	0.869	72	0.951	3.078
11	0.191	0.194	42	0.669	0.900	73	0.956	3.271
12	0.208	0.213	43	0.682	0.933	74	0.961	3.487
13	0.225	0.231	44	0.695	0.966	75	0.966	3.732
14	0.242	0.249	45	0.707	1.000	76	0.970	4.011
15	0.259	0.268	46	0.719	1.036	77	0.974	4.331
16	0.276	0.287	47	0.731	1.072	78	0.978	4.705
17	0.292	0.306	48	0.743	1.111	79	0.982	5.145
18	0.309	0.325	49	0.755	1.150	80	0.985	5.671
19	0.326	0.344	50	0.766	1.192	81	0.988	6.314
20	0.342	0.364	51	0.777	1.235	82	0.990	7.115
21	0.358	0.384	52	0.788	1.280	83	0.993	8.144
22	0.375	0.404	53	0.799	1.327	84	0.995	9.514
23	0.391	0.424	54	0.809	1.376	85	0.996	11.43
24	0.407	0.445	55	0.819	1.428	86	0.998	14.30
25	0.423	0.466	56	0.829	1.483	87	0.999	19.08
26	0.438	0.488	57	0.839	1.540	88	0.999	28.64
27	0.454	0.510	58	0.848	1.600	89	1.000	57.29
28	0.469	0.532	59	0.857	1.664	90	1.000	Infinity
29	0.485	0.554	60	0.866	1.732			
30	0.500	0.577	61	0.875	1.804			

Table 9: Index of Refraction.

(Temperature 20°C., standard pressure)

Air, dry, 0°C.	1.00029	Carbon tetrachloride	1.46	Glass, flint	1.61
Alcohol, ethyl	1.36	Diamond	2.42	Quartz, fused	1.46
Carbondisulphide	1.63	Glass, crown	1.52	Water	1.33

Table 10: Length of Light Waves.

Very dark red	7000Å	Green	5400Å
Red	6500Å	Bluish green	5000Å
Reddish orange	6400Å	Blue	4700Å
Orange	6100Å	Indigo	4300Å
Yellow	5800Å	Violet	4000Å

Å = Angstrom Units

GLOSSARY

Absorption spectrum

A spectrum having dark lines because of the absorption of some wave-lengths.

Achromatic lens

Combination of lenses that minimizes colour effects.

Amplitude

The greatest distance the medium of a wave is displaced from its position when at rest.

Amplitude modulation (AM)

Variation of a carrier wave by changes in the amplitude of the wave.

Angle of incidence

Angle between the perpendicular to a surface and the incident ray.

Angle of reflection

Angle between the perpendicular to a surface and the reflected ray.

Angle of refraction

Angle between the perpendicular to a surface and the refracted ray.

Archimedes' principle

Principle that any object floating or submerged in a fluid is buoyed up by a force equal to the weight of the displaced fluid.

Astigmatism

Failure of eye to see clearly because of lack of symmetry of eye lens or of cornea.

Atmospheric refraction

Bending of light rays by atmosphere.

Atom

Smallest particle of an element that enters into the composition of molecules.

Atomic number

Number equal to the number of protons in the nucleus of the atom.

Atomic weight or mass

Weight or mass of an atom relative to the mass of an oxygen atom taken as 16.

Binocular

Referring to vision with two eyes.

Blind spot

Point in retina where optic nerve enters.

Bright-line spectrum

Spectrum containing coloured lines used for identification of elements.

Candlepower

Unit of luminous intensity.

Centre of gravity

The point at which the resultant of the force of gravity on all parts of a body acts.

Chromatic aberration

Defect of lenses in not refracting all wave-lengths to the same focus.

Colour blindness

Inability to distinguish colours.

Colour wheel

Device used to combine colours.

Complementary colours

Colours which combine to produce sensation of white light.

Compound microscope

Microscope with two sets of lenses.

Concave lens

Lens with concave surfaces which diverges parallel rays.

Concave mirror

Mirror with concave surface which converges parallel rays.

Convex lens

Lens with convex surfaces which converges parallel rays.

Convex mirror

Mirror with convex surface which diverges parallel rays.

Critical angle

Angle of incidence for which the angle of refraction is 90 degrees.

Dark-line spectrum

Spectrum containing dark lines because of absorption of some wave-lengths.

Density

Mass per unit volume.

Diffuse reflection

Reflection from rough surfaces.

Dispersion

Separation of white light into colours.

Displacement

Weight of water displaced by an object when floating.

Eclipse

The passing of one heavenly body into the shadow of another.

Efficiency

Ratio of output work to input work.

Electromagnetic spectrum

Complete array of known electromagnetic radiations.

Electron

Smallest unit of negative electric charge.

Electron microscope

Microscope using a beam of electrons to form an image.

Energy

The capacity for doing work.

Exposure meter

Meter for reading light intensity for photographic purposes.

Farsightedness

Condition of eye because of which objects nearby cannot be seen clearly.

Fluid

Liquid or gas.

Fluorescence

Light brought about by radiation from ultraviolet rays.

Focal length

Distance from an optical device to the point where it focuses parallel rays.

GLOSSARY

Focus

Point to which an optical device directs parallel rays.

Foot-candle

Illumination at a distance one foot from a light source of one candlepower. A lumen per square foot.

Foot-pound

Unit of work.

Fraunhofer lines

Dark lines in the spectrum of sunlight.

Frequency

Number of vibrations per second in wave motion.

Hooke's Law

Law that stretch is proportional to the force applied.

Horsepower

Unit of power equal to 550 ft. lb. per sec.

Iconoscope

The camera tube in television.

Illumination

The luminous flux upon a surface of unit area.

Illumination meter

Meter indicating light intensity.

Incandescence

Glowing of a substance at high temperature.

Incident

Falling on; used with radiation.

Index of refraction

Ratio of speed of light in air to speed in medium.

Infra-red rays

Waves longer than waves of ordinary light but shorter than radio waves.

Kinescope

TV picture tube.

Light-year

Astronomical unit of distance equal to distance light travels in one year's time.

Linear scale

Scale which progresses arithmetically.

Litre

Unit of volume in the metric system.

Lumen

A unit of luminous flux equal to the flux on a unit surface all points of which are at a unit distance from a uniform point source of one candle.

Malleability

Ability of a substance to be hammered into thin sheets.

Mass

Defined tentatively as quantity of matter, but strictly a measure of the inertia of a body.

Mechanical advantage

Ratio of output force to input force.

Microwaves

Waves from about 1 to 3 cm. in length.

Millibar

One-thousandth of a bar. (1 bar = 760 mm. of mercury approx.)

Mirage

Optical illusion produced by layer of heated air.

Molecule

The smallest particle of a substance that has the properties of the substance.

Monochromatic

Referring to light of one colour only.

Nearsightedness

Condition of eyes by reason of which distant objects cannot be seen clearly.

Neutron

Neutral particle found in nucleus of atom.

Newton's rings

Coloured rings produced by the interference of light waves.

Nucleus

Central part of an atom.

Opera glass

Binocular telescope of low power.

Oscillator

Electric device which generates electric waves.

Oscillograph

Tracing on fluorescent screen of oscilloscope.

Pascal's law

Law that the pressure exerted on a confined fluid is transmitted undiminished in all directions.

Penumbra

Part of shadow receiving a portion of the light emitted by the light source.

Periscope

Device using mirrors to enable one to see round corners.

Photoelectric cell

Cell containing photoelectric material.

Photoelectric effect

Emission of electrons caused by incident light.

Photometer

Device used to compare light intensities.

Pinhole camera

A camera without a lens, light entering the camera through a pinhole.

Pound

Standard unit of mass in the British or F.P.S. system. Also a unit of force which gives a 1-lb. mass an acceleration of 32 ft. per sec. per sec.

Power

Rate of doing work.

Pressure

Force per unit area.

Primary colours

Red, green, and blue-violet, the three colours from which all possible colours can be obtained by proper mixing.

Principal axis

Line through centre of curvature and centre of a lens or mirror.

Principal focus

The point through which light rays parallel to the principal axis are reflected or refracted.

Prism binocular

Device consisting of two simple telescopes using prisms to produce an erect image.

Pupil

Opening in the eye through which light enters.

Quantum

Unit of energy proportional to frequency used in the quantum theory of radiation.

Radar

A device which operates by means of radio waves and their echoes.

Real image

Image formed by rays actually passing through it.

Refraction

Bending of light rays.

Regular reflection

Reflection from a polished surface.

Retina

Sensitive film forming back surface of eyeball.

Sine of an angle

With the given angle as an element of a right triangle, ratio of side opposite angle to hypotenuse.

Solar eclipse

Eclipse of the sun occurring when the moon passes between the earth and the sun.

Specific gravity

Ratio between the weight of an object and the weight of an equal volume of water.

Spectroscope

Instrument used in observing spectra.

Spectrum

Array of colours arranged according to their wave-lengths.

Spectrum, electromagnetic

Complete array of known electromagnetic radiations.

Spectrum analysis

Study of substances by observation of their spectra.

Spherical aberration

Defect of lenses and mirrors in not bringing parallel rays far from the principal axis to the same focus as nearer rays.

Total internal reflection

Reflection which occurs when the angle of incidence is greater than the critical angle.

Ultra-violet rays

Rays of shorter wave-length than visible light but longer than X-rays.

Umbra

Part of shadow which receives no light.

Velocity

Rate of motion in a particular direction.

Virtual image

Image formed by rays not actually passing through the position the image appears to occupy.

Visual angle

Angle formed by the two lines drawn from the extremities of an object to the centre of the eye.

Wave-length

Distance between corresponding points in two adjacent waves in a train of waves.

Weight

A measure of the force of attraction between the earth and a body near the earth.

Work

The product of a force and the distance through which the force acts.

ANSWERS

Unit I—Mechanics

CHAPTER 2, Section I : 4—Page 16

A

4 (a) 1000 mm., 100 cm., 10 dm., 1000 m. 5 (b) 1,000,000 mg., 100,000 cg., 10,000 dg., 1000 gm. 9 (b) 5, 5, 5, 5, 1, 3. 10 (b) 37., 34., 37. 11 (b) (i) 11.46 (ii) 8.3.

B

1 (a) 1520, 3.8, 605.4 cm.; (b) 30,000, 2.36, 60,005.44 sq. cm.; (c) 2,500,000, 2.3, 6,000,050.465 c.c. 2 (a) 37.4, 15.7, 39.4 in.; (b) (i) 30.5 cm. (ii) 1.61 km.; (c) 100 m. (i) 28.1 ft. (ii) 856 cm.; (d) (i) 58.7 ft. per sec. (ii) 17.9 m. per sec. (iii) 64.4 km. per hr. 3 (a) (i) 1500 sq. cm. (ii) 15. sq. dm.; (b) (i) 22,500 c.c. (ii) 22.5 cu. dm. (iii) 22.5 litres 4 (a) 22,500 gm., 22,500,000 mg., 2,250,000 cg., 225,000 dg., 22.5 kg.; (b) (i) 28.4 gm. (ii) 909. kg. 5 (i) 3.1 litres (ii) 3080 ml. (iii) 5.4 pints 6 (a) 102.70; (b) (i) 66.56 (ii) 71.25 (iii) 67.17; (c) (i) 36. (ii) 0.35 (iii) 27×10^1 ; (d) (i) 14×10^2 (ii) 0.50 (iii) 9.0

CHAPTER 3, Section I : 9—Page 22

A

1 (b) 2.70 gm. per c.c. 3 (b) 8.0.

B

1 5 gm. per c.c. 2 52.5 or 53. gm. 3 268 c.c. 4 62.5 or 63. lb. per cu. ft. 5 64. lb. 6 20.3 cu. ft. 7 4.87 8 54.1 c.c. 9 800 or 8×10^2 gm. 10 0.068 11 0.59 cu. ft. 12 1781.3 or 18×10^2 lb. 13 7.64 gm. per c.c. 14 0.8722 15 0.80 16 72.8 gm. 17 8.5 gm. per c.c. 18 (a) 19.5% (b) 13.4% 19 0.42 c.c. 20 5.9 or 6. gm. per c.c. 21 9.9 gm. per c.c. 22 8.7 gm. per c.c. 23 0.9 gm. per c.c. 24 1.18 gm. per c.c.

CHAPTER 4, Section I : 15—Page 32

A

1 (b) (i) 100 gm. (ii) 790 gm. 3 (c) (i) 2.6 gm. (ii) 4.3 c.c

B

1 (a) 30 gm.; (b) 162.5 lb. 2 (a) 68 gm.; (b) 625.0 lb. 3 (a) 25 ml. (b) 0.40 cu. ft. 4 10.5 5 (i) 7.14 (ii) 70 c.c. 6 (i) 2.5 (ii) 0.096 cu. ft. (iii) 156 lb. per cu. ft. 7 (i) 105.9 gm. (ii) 8.30 gm. per c.c. 8 1.30 9 (i) 5.36 (ii) 0.73 10 8.90, 0.840 11 32.0 gm. 12 No 13 120 gm. 14 0.9 gm. per c.c. 15 156. or 1.6×10^2 lb. 16 36.6 or 37. gm. 17 11.7 c.c. 18 0.90 gm. per c.c. 19 1.3 20 18.8 or 19. cm. 21 20.4 or 20 cm. 22 100 gm. 23 187.5 or 188. c.c. 24 0.21 25 $\frac{1}{3}$ 26 14. cm.

CHAPTER 5, Section I : 22—Page 39

A

7 $F = 1$ lb. wt.

B

1 24 ft. 2 300 ft. 3 40 lb. wt. 4 1200 miles 5 125 gm. wt. 6 (a) 21 ft. lb. wt.

ANSWERS

(b) 2,475 ft. lb. wt. (c) 36 ft. lb. wt. 7 (a) 6,900 ft. lb. wt. (b) 1,500 ft. lb. wt.
 8 31,400 ft. lb. wt. 9 700 ft. lb. wt. 10 (a) 3,600 ft. lb. wt. (b) 0.65 h.p. 11 (a)
 316,800 ft. lb. wt. (b) 1.9 h.p. 12 0.1 h.p. 13 0.02 h.p. 14 16 h.p. 15 0.88 h.p.
 16 0.5 h.p. 17 5 lb. wt. 18 20 sec. 19 330 ft. 20 2 sec. 21 49.5 tons 22 60
 m.p.h. 23 60 ft. 24 1,000 cu. ft. 25 0.27 h.p. 26 1.8 h.p. 27 375,000 h.p.
 28 28.4 h.p. 29 40.6 h.p. 30 792 cu. ft. 31 990 tons 32 36 h.p. 33 4×10^6 h.p.
 34 39,250 ft. lb. wt. 35 400 h.p. 36 800 ft.

Unit II—Light

CHAPTER 7, Section II : 8—Page 70

A

5 (d) 2 in. 7 (b) 8.3 min.

B

1 30 ft. 2 0.8 in. 3 148 or 1.5×10^2 m. 4 1.3 sec. 5 5.87×10^{12} miles, 9.46×10^{12}
 km. 6 52.8×10^{12} miles 7 4.3 years.

CHAPTER 8, Section II : 15—Page 77

B

1 0.5 ft.-cdl. 2 250 cdl. 3 32 ft.-cdl. 4 31.5 sec. 5 0.8 ft.-cdl. 6 36 cdl. 7 $1/16$
 ft.-cdl. 8 4 ft.-cdl. 9 90 c.p. 10 5 ft. 11 (a) 12.6 lumens (b) 50.3 lumens
 12 6 ft.-cdl. 13 8.9 cdl. 14 4 ft. 15 0.9 cdl. per watt 16 3 ft. from the 25 c.p.
 source 17 2.5 cdl. 18 1,600,000,000 ft.-cdl. 19 1.00 ft. and 3.0 ft. 20 2 ft. 21
 (a) 50.3 lumens (b) 201.1 sq. ft. (c) 0.25 lumens per sq. ft.

CHAPTER 9, Section II : 27—Page 91

A

5 (a) 7

B

1 (i) 10 o'clock (ii) 5.45 o'clock 4 (a) (i) 50 cm. (ii) 60 cm. (iii) 90 cm. (iv)
 $\propto$ (v) —60 cm. 5 —9.23 in. 6 3 ft. 7 4 in. 8 4.3 ft. 9 3 in. 10 36 cm.
 11 —4.5 in. 12 —8.6 cm. 13 20 in. 14 2.2 in.

CHAPTER 10, Section II : 41—Page 108

A

2 (c) 124,000 miles per sec.; (d) 2.47 5 (b) glass 7 (b) water 9 (d) 6.7
 dioptries.

B

1 1.20 2 479×10^2 miles per sec. 3 (i) 35° (ii) 28° (iii) 20° 4 $\angle i = 48.5^\circ$
 $\angle D = 37^\circ$ 5 One with critical angle of 30° 6 (a) (i) 50 cm. (ii) 60 cm.
 (iii) 90 cm. (iv) $\propto$ (v) —60 cm. 7 —9.2 in. 8 5 cm. 9 9 metres 10 $80 \times$
 11 32 in. 12 24 cm. 13 6 in. 14 24 cm. 15 —20 cm. 16 140, 12.7 cm. 17
 (i) 0.9 in. (ii) $11 \times$ 18 (a) 5.5 in.; (b) 36 in. $\times$ 60 in.

CHAPTER 11, Section II : 50—Page 122

1 (c) 7.3×10^{14} v.p.s.

CHAPTER 12, Section II : 57—Page 132

3 (a) 3.1 in.; (b) 1.5 in. 6 (c) (i) $8.3 \times$ (ii) $6.7 \times$ (d) (i) 25 mm. (ii) 20 mm.
 7 (b) $160 \times$ 9 (d) 192 cm.

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